ON

THE CONNECTION

OF

THE PHYSICAL SCIENCES.

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PREFACE.

THE progress of modern science, especially within the last few years, has been remarkable for a tendency to simplify the laws of nature, and to unite detached branches by general principles. In some cases identity has been proved where there appeared to be nothing in common, as in the electric and magnetic influences; in others, as that of light and heat, such analogies have been pointed out as to justify the expectation that they will ultimately be referred to the same agent, and in all there exists such a bond of union, that proficiency cannot be attained in any one without a knowledge of others.

Although well aware that a far more extensive illustration of these views might have been given, the Author hopes that enough has been done to show the Connection of the Physical Sciences.

In order to keep pace with the progress of discovery in various branches of the Physical Sciences, this book has been carefully revised.

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CONNECTION OF PHYSICAL SCIENCES.

INTRODUCTION.

SCIENCE, regarded as the pursuit of truth, must ever afford occupation of consummate interest, and subject of elevated meditation. The contemplation of the works of creation elevates the mind to the admiration of whatever is great and noble; accomplishing the object of all study, which, in the eloquent language of Sir James Mackintosh, "is to inspire the love of truth, of wisdom, of beauty—especially of goodness, the highest beauty —and of that supreme and eternal Mind, which contains all truth and wisdom, all beauty and goodness. By the love or delightful contemplation and pursuit of these transcendent aims, for their own sake only, the mind of man is raised from low and perishable objects, and prepared for those high destinies which are appointed for all those who are capable of them."

Astronomy affords the most extensive example of the connection of the physical sciences. In it are combined the sciences of number and quantity, of rest and motion. In it we perceive the operation of a force which is mixed up with everything that exists in the heavens or on earth; which pervades every atom, rules the motions of animate and inanimate beings, and is as sensible in the descent of a rain-drop as in the falls of Niagara; in the weight of the air, as in the periods of the moon. Gravitation not only binds satellites to their planet, and planets to the sun, but it connects sun with sun throughout the wide extent of creation, and is the cause of the disturbances, as well as of the order of nature: since every tremor it excites in any one planet is immediately transmitted to the farthest limits of the system, in oscillations, which correspond in their periods with the cause producing them, like sympathetic notes in music, or vibrations from the deep tones of an organ.

The heavens afford the most sublime subject of study which can be derived from science. The magnitude

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and splendor of the objects, the inconceivable rapidity
with which they move, and the enormous distances
between them, impress the mind with some notion of
the energy that maintains them in their motions, with a
durability to which we can see no limit.   Equally con-
spicuous is the goodness of the great First Cause, in
having endowed man with faculties, by which he can
not only appreciate the magnificence of His works, but
trace, with precision, the operation of His laws, use the
globe he inhabits as a base wherewith to measure the
magnitude and distance of the sun and planets, and
make the diameter (Note 1) of the earth's orbit the
first step of a scale by which he may ascend to the
starry firmament.   Such pursuits, while they ennoble
the mind, at the same time inculcate humility, by show-
ing that there is a barrier which no energy, mental or
physical, can ever enable us to pass: that, however
profoundly we may penetrate the depths of space,
there still remain innumerable systems, compared with
which, those apparently so vast must dwindle into in-
significance, or even become invisible; and that not only
man, but the globe he inhabits—nay, the whole system
of which it forms so small a part—might be annihilated,
and its extinction be unperceived in the immensity of
creation.

   A complete acquaintance with physical astronomy
can be attained by those only who are well versed in
the higher branches of mathematical and mechanical
science (N. 2), and they alone can appreciate the ex-
treme beauty of the results, and of the means by which
these results are obtained.   It is nevertheless true, that
a sufficient skill in analysis (N. 3) to follow the general
outline—to see the mutual dependence of the different
parts of the system, and to comprehend by what means
the most extraordinary conclusions have been arrived
at,—is within the reach of many who shrink from the
task, appalled by difficulties, not more formidable than
those incident to the study of the elements of every
branch of knowledge.   There is a wide distinction be-
tween the degree of mathematical acquirement neces-
sary for making discoveries, and that which is requisite
for understanding what others have done.

Our knowledge of external objects is founded upon experience, which furnishes facts; the comparison of these facts establishes relations, from which the belief that like causes will produce like effects, leads to general laws. Thus, experience teaches that bodies fall at the surface of the earth with an accelerated velocity, and with a force proportional to their masses. By comparison, Newton proved that the force which occasions the fall of bodies at the earth's surface is identical with that which retains the moon in her orbit; and he concluded, that as the moon is kept in her orbit by the attraction of the earth, so the planets might be retained in their orbits by the attraction of the sun. By such steps he was led to the discovery of one of those powers, with which the Creator has ordained, that matter should reciprocally act upon matter.

Physical astronomy is the science which compares and identifies the laws of motion observed on earth, with the motions that take place in the heavens; and which traces, by an uninterrupted chain of deduction from the great principle that governs the universe, the revolutions and rotations of the planets, and the oscillations (N. 4) of the fluids at their surfaces; and which estimates the changes the system has hitherto undergone, or may hereafter experience—changes which require millions of years for their accomplishment.

The accumulated efforts of astronomers, from the earliest dawn of civilization, have been necessary to establish the mechanical theory of astronomy. The courses of the planets have been observed for ages, with a degree of perseverance that is astonishing, if we consider the imperfection and even the want of instruments. The real motions of the earth have been separated from the apparent motions of the planets; the laws of the planetary revolutions have been discovered; and the discovery of these laws has led to the knowledge of the gravitation (N. 5) of matter. On the other hand, descending from the principle of gravitation, every motion in the solar system has been so completely explained, that the laws of any astronomical phenomena that may hereafter occur, are already determined.

SECTION I.

Attraction of a Sphere—Form of Celestial Bodies—Terrestrial Gravitation
retains the Moon in her Orbit—The Heavenly Bodies move in Conic
Sections—Gravitation proportional to Mass—Gravitation of the Particles
of Matter—Figure of the Planets—How it affects the Motions of their
Satellites—Rotation and Translation impressed by the same Impulse—
Motion of the Sun and Solar System.

It has been proved by Newton, that a particle of mat-
ter (N. 6) placed without the surface of a hollow sphere
(N. 7), is attracted by it in the same manner as if the
mass of the hollow sphere, or the whole matter it con-
tains, were collected into one dense particle in its center.
The same is therefore true of a solid sphere, which may
be supposed to consist of an infinite number of concentric
hollow spheres (N. 8). This, however, is not the case
with a spheroid (N. 9); but the celestial bodies are so
nearly spherical, and at such remote distances from one
another, that they attract and are attracted· as if each
were condensed into a single particle situate in its center
of gravity (N. 10)—a circumstance which greatly facili-
·tates the investigation of their motions.

Newton has shown that the force which retains the
moon in her orbit, is the same with that which causes
heavy substances to fall at the surface of the earth. If
the earth were a sphere, and at rest, a body would be
equally attracted, that is, it would have the same weight
at every point of its surface, because the surface of a
sphere is everywhere equally distant from its center.
But as our planet is flattened at the poles (N. 11), and
bulges at the equator, the weight of the same body
gradually decreases from the poles, where it is greatest,
to the equator, where it is least. There is, however, a
certain mean (N. 12) latitude (N. 13), or part of the earth
intermediate between the pole and the equator, where
the attraction of the earth on bodies at its surface is the
same as if it were a sphere; and experience shows that
bodies there fall through 16·0697 feet in a second. The
mean distance (N. 14) of the moon from the earth is
about sixty times the mean radius (N. 15) of the earth.
When the number 16·0697 *is diminished in the ratio*

that form in order to remain in equilibrio. The surface of the sea is therefore spheroidal, and the surface of the earth only deviates from that figure where it rises above or sinks below the level of the sea. But the deviation is so small, that it is unimportant when compared with the magnitude of the earth; for the mighty chain of the Andes, and the yet more lofty Himalaya, bear about the same proportion to the earth that a grain of sand does to a globe three feet in diameter. Such is the form of the earth and planets. The compression (N. 31) or flattening at their poles is, however, so small, that even Jupiter, whose rotation is the most rapid, and therefore the most elliptical of the planets, may, from his great distance, be regarded as spherical. Although the planets attract each other as if they were spheres, on account of their distances, yet the satellites (N. 32) are near enough to be sensibly affected in their motions by the forms of their primaries. The moon, for example, is so near the earth, that the reciprocal attraction between each of her particles, and each of the particles in the prominent mass at the terrestrial equator, occasions considerable disturbances in the motions of both bodies; for the action of the moon on the matter at the earth's equator, produces a nutation (N. 33) in the axis (N. 34) of rotation, and the reaction of that matter on the moon is the cause of a corresponding nutation in the lunar orbit (N. 35).

If a sphere at rest in space receive an impulse passing through its center of gravity, all its parts will move with an equal velocity in a straight line; but if the impulse does not pass though the center of gravity, its particles, having unequal velocities, will have a rotatory or revolving motion, at the same time that it is translated (N. 36) in space. These motions are independent of one another; so that a contrary impulse, passing through its center of gravity, will impede its progress, without interfering with its rotation. As the sun rotates about an axis, it seems probable, if an impulse in a contrary direction has not been given to his center of gravity, that he moves in space, accompanied by all those bodies which compose the solar system—a circumstance which would in no way interfere with their relative motions; for, in consequence of the principle, that force is proportional

to velocity (N. 37), the reciprocal attractions of a system
remain the same, whether its center of gravity be at
rest, or moving uniformly in space.   It is computed that,
had the earth received its motion from a single impulse,
that impulse must have passed through a point about
twenty-five miles from its center.

   Since the motions of rotation and translation of the
planets are independent of each other, though probably
communicated by the same impulse, they form separate
subjects of investigation.

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SECTION II.

Elliptical Motion—Mean and True Motion—Equinoctial—Ecliptic—Equi-
   noxes—Mean and True Longitude—Equation of Center—Inclination of
   the Orbits of Planets—Celestial Latitude—Nodes—Elements of an Orbit
   —Undisturbed or Elliptical Orbits—Great Inclination of the Orbits of
   the new Planets—Universal Gravitation the Cause of Perturbations in
   the Motions of the Heavenly Bodies—Problem of the Three Bodies—
   Stability of Solar System depends upon the Primitive Momentum of the
   Bodies.

   A PLANET moves in its elliptical orbit with a velocity
varying every instant, in consequence of two forces, one
tending to the center of the sun, and the other in the
direction of a tangent (N. 38) to its orbit, arising from
the primitive impulse, given at the time when it was
launched into space.   Should the force in the tangent
cease, the planet would fall to the sun by its gravity.
Were the sun not to attract it, the planet would fly off
in the tangent.   Thus, when the planet is at the point
of its orbit farthest from the sun, his action overcomes
the planet's velocity, and brings it toward him with
such an accelerated motion, that at last it overcomes the
sun's attraction; and shooting past him, gradually de-
creases in velocity, until it arrives at the most distant
point, where the sun's attraction again prevails (N. 39).
In this motion the *radii vectores* (N. 40), or imaginary
lines joining the centers of the sun and the planets, pass
over equal areas or spaces in equal times (N. 41).

   The mean distance of a planet from the sun is equal
to half the major axis (N. 42) of its orbit: if, therefore,
the planet described a circle (N. 43) round the sun at

its mean distance, the motion would be uniform, and
the periodic time unaltered, because the planet would
arrive at the extremities of the major axis at the same
instant, and would have the same velocity, whether it
moved in the circular or elliptical orbit, since the curves
coincide in these points. But, in every other part, the
elliptical or true motion (N. 44) would either be faster
or slower than the circular or mean motion (N. 45). As
it is necessary to have some fixed point in the heavens
from whence to estimate these motions, the vernal equi-
nox (N. 46) at a given epoch has been chosen. The
equinoctial, which is a great circle traced in the starry
heavens by the imaginary extension of the plane of the
terrestrial equator, is intersected by the ecliptic, or ap-
parent path of the sun, in two points diametrically oppo-
site to one another, called the vernal and autumnal
equinoxes. The vernal equinox is the point through
which the sun passes, in going from the southern to the
northern hemisphere; and the autumnal, that in which
he crosses from the northern to the southern. The
mean or circular motion of a body, estimated from the
vernal equinox, is its mean longitude; and its elliptical,
or true motion, reckoned from that point, is its true lon-
gitude (N. 47): both being estimated from west to east,
the direction in which the bodies move. The difference
between the two is called the equation of the center
(N. 48); which consequently vanishes at the apsides
(N. 49), or extremities of the major axis, and is at its
maximum ninety degrees (N. 50) distant from these
points, or in quadratures (N. 51), where it measures
the eccentricity (N. 52) of the orbit; so that the place
of a planet in its elliptical orbit is obtained, by adding or
subtracting the equation of the center to or from its
mean longitude.

The orbits of the planets have a very small obliquity
or inclination (N. 53) to the plane of the ecliptic in which
the earth moves; and on that account, astronomers refer
their motions to this plane at a given epoch as a known
and fixed position. The angular distance of a planet
from the plane of the ecliptic is its latitude (N. 54);
which is south or north, according as the planet is south
or north of that plane. When the planet is in the plane

of the ecliptic, its latitude is zero : it is then said to be
in its nodes (N. 55).   The ascending node is that point
in the ecliptic, through which the planet passes, in going
from the southern to the northern hemisphere.   The
descending node is a corresponding point in the plane of
the ecliptic diametrically opposite to the other, through
which the planet descends in going from the northern
to the southern hemisphere.   The longitude and lati-
tude of a planet cannot be obtained by direct observa-
tion, but are deduced from observations made at the
surface of the earth, by a very simple computation.
These two quantities, however, will not give the place
of a planet in space.   Its distance from the sun (N. 56)
must also be known; and, for the complete determina-
tion of its elliptical motion, the nature and position of its
orbit must be ascertained by observation.   This depends
upon seven quantities, called the elements of the orbit
(N. 57).   These are, the length of the major axis, and
the eccentricity, which determine the form of the orbit:
the longitude of the planet when at its least distance
from the sun, called the longitude of the perihelion; the
inclination of the orbit to the plane of the ecliptic, and
the longitude of its ascending node; these give the po-
sition of the orbit in space ; but the periodic time, and
the longitude of the planet at a given instant, called the
longitude of the epoch, are necessary for finding the
place of the body in its orbit at all times.   A perfect
knowledge of these seven elements is requisite, for as-
certaining all the circumstances of undisturbed elliptical
motion.   By such means it is found, that the paths of
the planets, when their mutual disturbances are omitted,
are ellipses nearly approaching to circles, whose planes,
slightly inclined to the ecliptic, cut it in straight lines,
passing through the center of the sun (N. 58).   The
orbits of the recently discovered planets deviate more
from the ecliptic than those of the ancient planets; that
of Pallas, for instance, has an inclination of 34° 37′ 50·2″
to it; on which account it is more difficult to determine
their motions.

    Were the planets attracted by the sun only, they
would always move in ellipses, invariable in form and
position; and because his action is proportional to his

mass, which is much larger than that of all the planets put together, the elliptical is the nearest approximation to their true motions.   The true motions of the planets are extremely complicated, in consequence of their mutual attraction: so that they do not move in any known or symmetrical curve, but in paths now approaching to, now receding from, the elliptical form: and their radii vectores do not describe areas or spaces exactly proportional to the time, so that the areas become a test of disturbing forces.

To determine the motion of each body, when disturbed by all the rest, is beyond the power of analysis. It is therefore necessary to estimate the disturbing action of one planet at a time, whence the celebrated problem of the three bodies, originally applied to the moon, the earth, and the sun: namely, the masses being given of three bodies projected from three given points, with velocities given both in quantity and direction: and, supposing the bodies to gravitate to one another with forces that are directly as their masses, and inversely as the squares of the distances, to find the lines described by these bodies, and their positions at any given instant: or, in other words, to determine the path of a celestial body when attracted by a second body, and disturbed in its motion round the second body by a third—a problem equally applicable to planets, satellites, and comets.

By this problem the motions of translation of the celestial bodies are determined.   It is an extremely difficult one, and would be infinitely more so, if the disturbing action were not very small when compared with the central force: that is, if the action of the planets on one another were not very small, when compared with that of the sun.   As the disturbing influence of each body may be found separately, it is assumed that the action of the whole system, in disturbing any one planet, is equal to the sum of all the particular disturbances it experiences, on the general mechanical principle, that the sum of any number of small oscillations is nearly equal to their simultaneous and joint effect.

On account of the reciprocal action of matter, the stability of the system depends upon the intensity of the

primitive momentum (N. 59) of the planets, and the ratio of their masses to that of the sun; for the nature of the conic sections in which the celestial bodies move, depends upon the velocity with which they were first propelled in space. Had that velocity been such as to make the planets move in orbits of unstable equilibrium (N. 60), their mutual attractions might have changed them into parabolas, or even hyperbolas (N. 22); so that the earth and planets might ages ago, have been sweeping far from our sun through the abyss of space. But as the orbits differ very little from circles, the momentum of the planet, when projected, must have been exactly sufficient to insure the permanency and stability of the system. Besides, the mass of the sun is vastly greater than that of any planet; and as their inequalities bear the same ratio to their elliptical motions, that their masses do to that of the sun, their mutual disturbances only increase or diminish the eccentricities of their orbits, by very minute quantities; consequently the magnitude of the sun's mass is the principal cause of the stability of the system. There is not in the physical world a more splendid example of the adaptation of means to the accomplishment of an end, than is exhibited in the nice adjustment of these forces, at once the cause of the variety and of the order of Nature.

SECTION III.

THE planets are subject to disturbances of two kinds, both resulting from the constant operation of their reciprocal attraction: one kind, depending upon their posi-

tions with regard to each other, begins from zero, increases to a maximum, decreases, and becomes zero again, when the planets return to the same relative positions. In consequence of these, the disturbed planet is sometimes drawn away from the sun, sometimes brought nearer to him: sometimes it is accelerated in its motion, and sometimes retarded. At one time it is drawn above the plane of its orbit, at another time below it, according to the position of the disturbing body. All such changes, being accomplished in short periods, some in a few months, others in years, or in hundreds of years, are denominated periodic inequalities. The inequalities of the other kind, though occasioned likewise by the disturbing energy of the planets, are entirely independent of their relative positions. They depend upon the relative positions of the orbits alone, whose forms and places in space are altered by very minute quantities, in immense periods of time, and are, therefore, called secular inequalities.

The periodical perturbations are compensated, when the bodies return to the same relative positions with regard to one another and to the sun: the secular inequalities are compensated, when the orbits return to the same positions relatively to one another, and to the plane of the ecliptic.

Planetary motion, including both these kinds of disturbance, may be represented by a body revolving in an ellipse, and making small and transient deviations, now on one side of its path, and now on the other, while the ellipse itself is slowly, but perpetually, changing both in form and position.

The periodic inequalities are merely transient deviations of a planet from its path, the most remarkable of which only lasts about 918 years; but, in consequence of the secular disturbances, the apsides, or extremities of the major axes of all the orbits, have a direct but variable motion in space, excepting those of the orbit of Venus, which are retrograde (N. 61), and the lines of the nodes move with a variable velocity in a contrary direction. Besides these, the inclination and eccentricity of every orbit are in a state of perpetual but slow change. These effects result from the disturbing action

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of all the planets on each. But as it is only necessary
to estimate the disturbing influence of one body at a
time, what follows may convey some idea of the manner
in which one planet disturbs the elliptical motion of
another.

Suppose two planets moving in ellipses round the sun;
if one of them attracted the other and the sun with
equal intensity, and in parallel directions (N. 62), it
would have no effect in disturbing the elliptical motion.
The inequality of this attraction is the sole cause of
perturbation, and the difference between the disturbing
planet's action on the sun and on the disturbed planet
constitutes the disturbing force, which consequently
varies in intensity and direction with every change in
the relative positions of the three bodies. Although
both the sun and planet are under the influence of the
disturbing force, the motion of the disturbed planet is
referred to the center of the sun as a fixed point, for
convenience. The whole force (N. 63) which disturbs
a planet is equivalent to three partial forces. One of
these acts on the disturbed planet, in the direction of a
tangent to its orbit, and is called the tangential force : it
occasions secular inequalities in the form and position of
the orbit in its own plane, and is the sole cause of the
periodical perturbations in the planet's longitude. An-
other acts upon the same body in the direction of its
radius vector, that is, in the line joining the centers of
the sun and planet, and is called the radial force : it
produces periodical changes in the distance of the planet
from the sun, and affects the form and position of the
orbit in its own plane. The third, which may be called
the perpendicular force, acts at right angles to the plane
of the orbit, occasions the periodic inequalities in the
planet's latitude, and affects the position of the orbit
with regard to the plane of the ecliptic.

It has been observed, that the radius vector of a
planet moving in a perfectly elliptical orbit, passes over
equal spaces or areas in equal times; a circumstance
which is independent of the law of the force, and would
be the same whether it varied inversely as the square
of the distance, or not, provided only that it be directed
to the center of the sun. Hence the tangential force,

not being directed to the center, occasions an unequable description of areas, or, what is the same thing, it disturbs the motion of the planet in longitude. The tangential force sometimes accelerates the planet's motion, sometimes retards it, and occasionally has no effect at all. Were the orbits of both planets circular, a complete compensation would take place at each revolution of the two planets, because the arcs in which the accelerations and retardations take place, would be symmetrical on each side of the disturbing force. For it is clear, that if the motion be accelerated through a certain space, and then retarded through as much, the motion at the end of the time will be the same as if no change had taken place. But, as the orbits of the planets are ellipses, this symmetry does not hold ; for, as the planet moves unequably in its orbit, it is in some positions more directly, and for a longer time, under the influence of the disturbing force than in others. And although multitudes of variations do compensate each other in short periods, there are others, depending on peculiar relations among the periodic times of the planets, which do not compensate each other till after one, or even till after many revolutions of both bodies. A periodical inequality of this kind in the motions of Jupiter and Saturn, has a period of no less than 918 years.

The radial force, or that part of the disturbing force which acts in the direction of the line joining the centers of the sun and disturbed planet, has no effect on the areas, but is the cause of periodical changes of small extent in the distance of the planet from the sun. It has already been shown, that the force producing perfectly elliptical motion varies inversely as the square of the distance, and that a force following any other law would cause the body to move in a curve of a very different kind. Now, the radial disturbing force varies directly as the distance ; and, as it sometimes combines with and increases the intensity of the sun's attraction for the disturbed body, and at other times opposes and consequently diminishes it, in both cases it causes the sun's attraction to deviate from the exact law of gravity, and the whole action of this compound central force on the disturbed body is either greater or less than what is

requisite for perfectly elliptical motion. When greater, the curvature of the disturbed planet's path on leaving its perihelion (N. 64), or point nearest the sun, is greater than it would be in the ellipse, which brings the planet to its aphelion (N. 65), or point farthest from the sun, before it has passed through 180°, as it would do if undisturbed. So that in this case the apsides, or extremities of the major axis, advance in space. When the central force is less than the law of gravity requires, the curvature of the planet's path is less than the curvature of the ellipse. So that the planet, on leaving its perihelion, would pass through more than 180° before arriving at its aphelion, which causes the apsides to recede in space (N. 66). Cases both of advance and recess occur during a revolution of the two planets; but those in which the apsides advance, preponderate. This, however, is not the full amount of the motion of the apsides; part arises also from the tangential force (N. 63), which alternately accelerates and retards the velocity of the disturbed planet. An increase in the planet's tangential velocity diminishes the curvature of its orbit, and is equivalent to a decrease of central force. On the contrary, a decrease of the tangential velocity, which increases the curvature of the orbit, is equivalent to an increase of central force. These fluctuations, owing to the tangential force, occasion an alternate recess and advance of the apsides, after the manner already explained (N. 66). An uncompensated portion of the direct motion arising from this cause, conspires with that already impressed by the radial force, and in some cases even nearly doubles the direct motion of these points. The motion of the apsides may be represented, by supposing a planet to move in an ellipse, while the ellipse itself is slowly revolving about the sun in the same plane (N. 67). This motion of the major axis, which is direct in all the orbits except that of the planet Venus, is irregular, and so slow, that it requires more than 109,830 years for the major axis of the earth's orbit to accomplish a sidereal revolution (N. 68), that is, to return to the same stars; and 20,984 years to complete its tropical revolution (N. 69), or to return to the same equinox. The difference between these

two periods arises from a retrograde motion in the equinoctial point, which meets the advancing axis before it has completed its revolution with regard to the stars. The major axis of Jupiter's orbit requires no less than 200,610 years to perform its sidereal revolution, and 22,748 years to accomplish its tropical revolution from the disturbing action of Saturn alone.

A variation in the eccentricity of the disturbed planet's orbit, is an immediate consequence of the deviation from elliptical curvature, caused by the action of the disturbing force. When the path of the body, in proceeding from its perihelion to its aphelion, is more curved than it ought to be from the effect of the disturbing forces, it falls within the elliptical orbit, the eccentricity is diminished, and the orbit becomes more nearly circular; when that curvature is less than it ought to be, the path of the planet falls without its elliptical orbit (N. 66), and the eccentricity is increased : during these changes, the length of the major axis is not altered, the orbit only bulges out, or becomes more flat (N. 70). Thus the variation in the eccentricity arises from the same cause that occasions the motion of the apsides (N. 67). There is an inseparable connection between these two elements; they vary simultaneously, and have the same period; so that while the major axis revolves in an immense period of time, the eccentricity increases and decreases by very small quantities, and at length returns to its original magnitude at each revolution of the apsides. The terrestrial eccentricity is decreasing at the rate of about 40 miles annually ; and, if it were to decrease equably, it would be 39,861 years before the earth's orbit became a circle. The mutual action of Jupiter and Saturn occasions variations in the eccentricity of both orbits, the greatest eccentricity of Jupiter's orbit corresponding to the least of Saturn's. The period in which these vicissitudes are accomplished is 70,414 years, estimating the action of these two planets alone : but if the action of all the planets were estimated, the cycle would extend to millions of years.

That part of the disturbing force is now to be considered which acts perpendicularly to the plane of the orbit, causing periodic perturbations in latitude, secular

variations in the inclination of the orbit, and a retrograde motion to its nodes on the true plane of the ecliptic (N. 71). This force tends to pull the disturbed body above, or push (N. 72) it below, the plane of its orbit, according to the relative positions of the two planets with regard to the sun, considered to be fixed. By this action, it sometimes makes the plane of the orbit of the disturbed body tend to coincide with the plane of the ecliptic, and sometimes increases its inclination to that plane. In consequence of which, its nodes alternately recede or advance on the ecliptic (N. 73). When the disturbing planet is in the line of the disturbed planet's nodes (N. 74), it neither affects these points, the latitude, nor the inclination, because both planets are then in the same plane. When it is at right angles to the line of the nodes, and the orbit symmetrical on each side of the disturbing force, the average motion of these points, after a revolution of the disturbed body, is retrograde, and comparatively rapid; but when the disturbing planet is so situated that the orbit of the disturbed planet is not symmetrical on each side of the disturbing force, which is most frequently the case, every possible variety of action takes place. Consequently, the nodes are perpetually advancing or receding with unequal velocity; but, as a compensation is not effected, their motion is, on the whole, retrograde.

With regard to the variations in the inclination, it is clear, that, when the orbit is symmetrical on each side of the disturbing force, all its variations are compensated after a revolution of the disturbed body, and are merely periodical perturbations in the planet's latitude; and no secular change is induced in the inclination of the orbit. When, on the contrary, that orbit is not symmetrical on each side of the disturbing force, although many of the variations in latitude are transient or periodical, still, after a complete revolution of the disturbed body, a portion remains uncompensated, which forms a secular change in the inclination of the orbit to the plane of the ecliptic. It is true, part of this secular change in the inclination is compensated by the revolution of the disturbing body, whose motion has not hitherto been taken into the account, so that perturbation compensates per-

turbation; but still, a comparatively permanent change is effected in the inclination, which is not compensated till the nodes have accomplished a complete revolution.

The changes in the inclination are extremely minute (N. 75), compared with the motion of the nodes, and there is the same kind of inseparable connection between their secular changes that there is between the variation of the eccentricity and the motion of the major axis. The nodes and inclinations vary simultaneously, their periods are the same, and very great. The nodes of Jupiter's orbit, from the action of Saturn alone, require 36,261 years to accomplish even a tropical revolution. In what precedes, the influence of only one disturbing body has been considered; but when the action and re-action of the whole system is taken into account, every planet is acted upon, and does itself act, in this manner, on all the others; and the joint effect keeps the incli-nations and eccentricities in a state of perpetual variation. It makes the major axis of all the orbits continually re-volve, and causes, on an average, a retrograde motion of the nodes of each orbit upon every other. The ecliptic (N. 71) itself is in motion from the mutual action of the earth and planets, so that the whole is a compound phe-nomenon of great complexity, extending through un-known ages. At the present time the inclinations of all the orbits are decreasing, but so slowly, that the incli-nation of Jupiter's orbit is only about six minutes less than it was in the age of Ptolemy.

But, in the midst of all these vicissitudes, the length of the major axis and the mean motions of the planets remain permanently independent of secular changes. They are so connected by Kepler's law, of the squares of the periodic times being proportional to the cubes of the mean distances of the planets from the sun, that one cannot vary without affecting the other. And it is proved, that any variations which do take place are transient, and depend only on the relative positions of the bodies.

It is true that, according to theory, the radial disturb-ing force should permanently alter the dimensions of all the orbits, and the periodic times of all the planets, to a certain degree. For example, the masses of all the

planets revolving within the orbit of any one, such as
Mars, by adding to the interior mass, increase the at-
tracting force of the sun, which, therefore, must con-
tract the dimensions of the orbit of that planet, and di-
minish its periodic time ; while the planets exterior to
Mars' orbit must have the contrary effect. But the
mass of the whole of the planets and satellites taken to-
gether is so small, when compared with that of the sun,
that these effects are quite insensible, and could only
have been discovered by theory. And, as it is certain
that the length of the major axes and the mean motions
are not permanently changed by any other power what-
ever, it may be concluded that they are invariable.

With the exception of these two elements, it appears
that all the bodies are in motion, and every orbit in a
state of perpetual change. Minute as these changes
are, they might be supposed to accumulate in the course
of ages, sufficiently to derange the whole order of na-
ture, to alter the relative positions of the planets, to put
an end to the vicissitudes of the seasons, and to bring
about collisions which would involve our whole system,
now so harmonious, in chaotic confusion. It is natural
to inquire, what proof exists that nature will be pre-
served from such a catastrophe ? Nothing can be known
from observation, since the existence of the human race
has occupied comparatively but a point in duration,
while these vicissitudes embrace myriads of ages. The
proof is simple and conclusive. All the variations of
the solar system, secular as well as periodic, are ex-
pressed analytically by the sines and cosines of circular
arcs (N. 76), which increase with the time ; and, as a
sine or cosine can never exceed the radius, but must
oscillate between zero and unity, however much the
time may increase, it follows that, when the variations
have accumulated to a maximum, by slow changes, in
however long a time, they decrease, by the same slow
degrees, till they arrive at their smallest value, again to
begin a new course ; thus forever oscillating about a
mean value. This circumstance, however, would be
insufficient, were it not for the small eccentricities of
the planetary orbits, their minute inclinations to the
plane of the ecliptic, and the revolutions of all the bodies,

as well planets as satellites, in the same direction.
These secure the perpetual stability of the solar system
(N. 77).   The equilibrium, however, would be de-
ranged, if the planets moved in a resisting medium
(N. 78) sufficiently dense to diminish their tangential
velocity, for then both the eccentricities and the major
axes of the orbits would vary with the time, so that the
stability of the system would be ultimately destroyed.
The existence of an ethereal fluid is now proved ; and
although it is so extremely rare that hitherto its effects
on the motions of the planets have been altogether in-
sensible, there can be no doubt that, in the immensity
of time, it will modify the forms of the planetary orbits,
and may at last even cause the destruction of our sys-
tem, which in itself contains no principle of decay, unless
a rotatory motion from west to east has been given to this
fluid by the bodies of the solar system, which have all
been revolving about the sun in that direction for un-
known ages.   This rotation, which seems to be highly
probable, may even have been coeval with its creation.
Such a vortex would have no effect on bodies moving
with it, but it would influence the motions of those re-
volving in a contrary direction.   It is possible that the
disturbances experienced by comets which have already
revealed the existence of this fluid, may also, in time,
disclose its rotatory motion.
   The form and position of the planetary orbits, and the
motion of the bodies in the same direction, together with
the periodicity of the terms in which the inequalities
are expressed, assure us that the variations of the sys-
tem are confined within very narrow limits, and that,
although we do not know the extent of the limits, nor
the period of that grand cycle which probably embraces
millions of years, yet they never will exceed what is
requisite for the stability and harmony of the whole, for
the preservation of which every circumstance is so beau-
tifully and wonderfully adapted.
   The plane of the ecliptic itself, though assumed to be
fixed at a given epoch for the convenience of astronomi-
cal computation, is subject to a minute secular variation
of $45''\cdot7$, occasioned by the reciprocal action of the plan-
ets.   But, as this is also periodical, and cannot exceed

2° 42′, the terrestrial equator, which is inclined to it at
an angle of 23° 27′ 34″·69, will never coincide with the
plane of the ecliptic : so there never can be perpetual
spring (N. 79). The rotation of the earth is uniform ;
therefore day and night, summer and winter, will con-
tinue their vicissitudes while the system endures, or is
undisturbed by foreign causes.

> "Yonder starry sphere
> Of planets and of fix'd, in all her wheels
> Resembles nearest mazes intricate,
> Eccentric, intervolved, yet regular,
> Then most, when most irregular they seem."

The stability of our system was established by La
Grange : "a discovery," says Professor Playfair, "that
must render the name forever memorable in science,
and revered by those who delight in the contemplation
of whatever is excellent and sublime." After Newton's
discovery of the mechanical laws of the elliptical orbits
of the planets, La Grange's discovery of their periodical
inequalities is, without doubt, the noblest truth in physi-
cal astronomy ; and in respect of the doctrine of final
causes, it may be regarded as the greatest of all.

Notwithstanding the permanency of our system, the
secular variations in the planetary orbits would have
been extremely embarrassing to astronomers when it
became necessary to compare observations separated by
long periods. The difficulty was in part obviated, and
the principle for accomplishing it established, by La
Place, and has since been extended by M. Poinsot. It
appears that there exists an invariable plane (N. 80),
passing through the center of gravity of the system,
about which the whole oscillates within very narrow
limits, and that this plane will always remain parallel to
itself, whatever changes time may induce in the orbits
of the planets, in the plane of the elliptic, or even in
the law of gravitation; provided only that our system
remains unconnected with any other. The position of
the plane is determined by this property—that, if each
particle in the system be multiplied by the area de-
scribed upon this plan in a given time, by the projection
of its radius vector about the common center of gravity
of the whole, the sum of all these products will be a

maximum (N. 81). La Place found that the plane in question is inclined to the ecliptic at an angle of nearly 1° 34′ 15″, and that, in passing through the sun, and about midway between the orbits of Jupiter and Saturn, it may be regarded as the equator of the solar system, dividing it into two parts, which balance one another in all their motions. This plane of greatest inertia, by no means peculiar to the solar system, but existing in every system of bodies submitted to their mutual attractions only, always maintains a fixed position, whence the oscillations of the system may be estimated through unlimited time. Future astronomers will know, from its immutability or variation, whether the sun and his attendants are connected or not with the other systems of the universe. Should there be no link between them, it may be inferred, from the rotation of the sun, that the center of gravity (N. 82) of the system situate within his mass describes a straight line in this invariable plane or great equator of the solar system, which, unaffected by the changes of time, will maintain its stability through endless ages. But, if the fixed stars, comets, or any unknown and unseen bodies, affect our sun and planets, the nodes of this plane will slowly recede on the plane of that immense orbit which the sun may describe about some most distant center, in a period which it transcends the powers of man to determine. There is every reason to believe that this is the case ; for it is more than probable that, remote as the fixed stars are, they in some degree influence our system, and that even the invariability of this plane is relative, only appearing fixed to creatures incapable of estimating its minute and slow changes during the small extent of time and space granted to the human race. "The development of such changes," as M. Poinsot justly observes, "is similar to an enormous curve, of which we see so small an arc, that we imagine it to be a straight line." If we raise our views to the whole extent of the universe, and consider the stars, together with the sun, to be wandering bodies, revolving about the common center of creation, we may then recognize in the equatorial plane passing through the center of gravity of the universe the only instance of absolute and eternal repose.

All the periodic and secular inequalities deduced from the law of gravitation are so perfectly confirmed by observation, that analysis has become one of the most certain means of discovering the planetary irregularities, either when they are too small, or too long in their periods, to be detected by other methods.   Jupiter and Saturn, however, exhibit inequalities which for a long time seemed discordant with that law.   All observations, from those of the Chinese and Arabs down to the present day, prove that for ages the mean motions of Jupiter and Saturn have been affected by a great inequality of a very long period, forming an apparent anomaly in the theory of the planets.   It was long known by observation that five times the mean motion of Saturn is nearly equal to twice that of Jupiter: a relation which the sagacity of La Place perceived to be the cause of a periodic irregularity in the mean motion of each of these planets, which completes its period in nearly 918 years, the one being retarded while the other is accelerated; but both the magnitude and period of these quantities vary in consequence of the secular variations in the elements of the orbits.   Suppose the two planets to be on the same side of the sun, and all three in the same straight line, they are then said to be in conjunction (N. 83).   Now, if they begin to move at the same time, one making exactly five revolutions in its orbit, while the other only accomplishes two, it is clear that Saturn, the slow-moving body, will only have got through a part of its orbit during the time that Jupiter has made one whole revolution and part of another, before they be again in conjunction.   It is found that during this time their mutual action is such as to produce a great many perturbations which compensate each other, but that there still remains a portion outstanding, owing to the length of time during which the forces act in the same manner; and if the conjunction always happened in the same point of the orbit, this uncompensated inequality in the mean motion would go on increasing till the periodic times and forms of the orbits were completely and permanently changed: a case that would actually take place if Jupiter accomplished exactly five revolutions in the time Saturn performed two.   These revolutions

are, however, not exactly commensurable ; the points in which the conjunctions take place are in advance each time as much as 8°·37 ; so that the conjunctions do not happen exactly in the same points of the orbits till after a period of 850 years ; and, in consequence of this small advance, the planets are brought into such relative positions that the inequality which seemed to threaten the stability of the system is completely compensated, and the bodies, having returned to the same relative positions with regard to one another and the sun, begin a new course.   The secular variations in the elements of the orbit increase the period of the inequality to 918 years (N. 84).   As any perturbation which affects the mean motion affects also the major axis, the disturbing forces tend to diminish the major axis of Jupiter's orbit and increase that of Saturn's during one half of the period, and the contrary during the other half.   This inequality is strictly periodical, since it depends upon the configuration (N. 85) of the two planets ; and theory is confirmed by observation, which shows that, in the course of twenty centuries, Jupiter's mean motion has been accelerated by about 3° 23′, and Saturn's retarded by 5° 13′.   Several instances of perturbations of this kind occur in the solar system.   One, in the mean motions of the Earth and Venus, only amounting to a few seconds, has been recently worked out with immense labor by Professor Airy.   It accomplishes its changes in 240 years, and arises from the circumstance of thirteen times the periodic time of Venus being nearly equal to eight times that of the Earth.   Small as it is, it is sensible in the motions of the Earth.

It might be imagined that the reciprocal action of such planets as have satellites would be different from the influence of those that have none.   But the distances of the satellites from their primaries are incomparably less than the distances of the planets from the sun, and from one another ; so that the system of a planet and its satellites moves nearly as if all these bodies were united in their common center of gravity.   The action of the sun, however, in some degree disturbs the motion of the satellites about their primary.

C

SECTION IV.

Theory of Jupiter's Satellites—Effects of the Figure of Jupiter upon his
  Satellites—Position of their Orbits—Singular Laws among the Motions
  of the first three Satellites—Eclipses of the Satellites—Velocity of Light
  —Aberration—Ethereal Medium—Satellites of Saturn and Uranus.

THE changes which take place in the planetary sys-
tem are exhibited on a smaller scale by Jupiter and his
satellites; and, as the period requisite for the develop-
ment of the inequalities of these moons only extends to
a few centuries, it may be regarded as an epitome of
that grand cycle which will not be accomplished by the
planets in myriads of ages.   The revolutions of the
satellites about Jupiter are precisely similar to those of
the planets about the sun: it is true they are disturbed
by the sun, but his distance is so great, that their
motions are nearly the same as if they were not under
his influence.   The satellites, like the planets, were
probably projected in elliptical orbits: but, as the masses
of the satellites are nearly 100,000 times less than that
of Jupiter; and as the compression of Jupiter's sphe-
roid is so great, in consequence of his rapid rotation,
that his equatorial diameter exceeds his polar diameter
by no less than 6000 miles; the immense quantity of
prominent matter at his equator must soon have given
the circular form observed in the orbits of the first and
second satellites, which its superior attraction will al-
ways maintain.   The third and fourth satellites, being
farther removed from its influence, revolve in orbits
with a very small eccentricity.   And although the first
two sensibly move in circles, their orbits acquire a
small ellipticity, from the disturbances they experience
(N. 86).
   It has been stated, that the attraction of a sphere on
an exterior body is the same as if its mass were united
in one particle in its center of gravity, and therefore
inversely as the square of the distance.   In a spheroid,
however, there is an additional force arising from the
bulging mass at its equator, which, not following the
exact law of gravity, acts as a disturbing force.   One

effect of this disturbing force in the spheroid of Jupiter
is, to occasion a direct motion in the greater axes of the
orbits of all his satellites, which is more rapid the
nearer the satellite is to the planet, and very much
greater than that part of their motion which arises from
the disturbing action of the sun. The same cause
occasions the orbits of the satellites to remain nearly in
the plane of Jupiter's equator (N. 87), on account of
which the satellites are always seen nearly in the same
line (N. 88); and the powerful action of that quantity
of prominent matter is the reason why the motions of
the nodes of these small bodies are so much more rapid
than those of the planet. The nodes of the fourth
satellite accomplish a tropical revolution in 531 years;
while those of Jupiter's orbit require no less than
36,261 years;—a proof of the reciprocal attraction be-
tween each particle of Jupiter's equator and of the
satellites. In fact, if the satellites moved exactly in the
plane of Jupiter's equator, they would not be pulled
out of that plane, because his attraction would be equal
on both sides of it. But, as their orbits have a small
inclination to the plane of the planet's equator, there
is a want of symmetry, and the action of the protuberant
matter tends to make the nodes regress by pulling the
satellites above or below the planes of their orbits; an
action which is so great on the interior satellites, that
the motions of their nodes are nearly the same as if no
other disturbing force existed.

The orbits of the satellites do not retain a permanent
inclination, either to the plane of Jupiter's equator, or
to that of his orbit, but to certain planes passing between
the two, and through their intersection. These have a
greater inclination to his equator the farther the satel-
lite is removed, owing to the influence of Jupiter's
compression; and they have a slow motion correspond-
ing to secular variations in the planes of Jupiter's orbit
and equator.

The satellites are not only subject to periodic and
secular inequalities from their mutual attraction, similar
to those which affect the motions and orbits of the
planets, but also to others peculiar to themselves. Of
the periodic inequalities arising from their mutual at-

traction, the most remarkable take place in the angular
motions (N. 89) of the three nearest to Jupiter, the
second of which receives from the first a perturbation
similar to that which it produces in the third ; and it
experiences from the third a perturbation similar to that
which it communicates to the first. In the eclipses
these two inequalities are combined into one, whose
period is 437·659 ^{days}. The variations peculiar to the
satellites arise from the secular inequalities occasioned
by the action of the planets in the form and position of
Jupiter's orbit, and from the displacement of his equator.
It is obvious that whatever alters the relative positions
of the sun, Jupiter, and his satellites, must occasion a
change in the directions and intensities of the forces,
which will affect the motions and orbits of the satellites.
For this reason the secular variations in the eccen-
tricity of Jupiter's orbit occasion secular inequalities in
the mean motions of the satellites, and in the motions
of the nodes and apsides of their orbits. The displace-
ment of the orbit of Jupiter, and the variation in the
position of his equator, also affect these small bodies
(N. 90). The plane of Jupiter's equator is inclined to
the plane of his orbit at an angle of 3° 5' 30", so that
the action of the sun and of the satellites themselves
produces a nutation and precession (N. 91) in his equa-
tor, precisely similar to that which takes place in the
rotation of the earth, from the action of the sun and
moon. Hence the protuberant matter at Jupiter's equa-
tor is continually changing its position with regard to
the satellites, and produces corresponding mutations in
their motions. And, as the cause must be proportional
to the effect, these inequalities afford the means, not
only of ascertaining the compression of Jupiter's sphe-
roid, but they prove that his mass is not homogeneous.
Although the apparent diameters of the satellites are
too small to be measured, yet their perturbations give
the values of their masses with considerable accuracy—
a striking proof of the power of analysis.

A singular law obtains among the mean motions and
mean longitudes of the first three satellites. It appears
from observation that the mean motion of the first
satellite, plus twice that of the third, is equal to three

times that of the second; and that the mean longitude of the first satellite, minus three times that of the second, plus twice that of the third, is always equal to two right angles. It is proved by theory, that if these relations had only been approximate when the satellites were first launched into space, their mutual attractions would have established and maintained them, notwithstanding the secular inequalities to which they are liable. They extend to the synodic motions (N. 92) of the satellites; consequently they affect their eclipses, and have a very great influence on their whole theory. The satellites move so nearly in the plane of Jupiter's equator, which has a very small inclination to his orbit, that the first three are eclipsed at each revolution by the shadow of the planet, which is much larger than the shadow of the moon: the fourth satellite is not eclipsed so frequently as the others. The eclipses take place close to the disc of Jupiter when he is near opposition (N. 93); but at times his shadow is so projected with regard to the earth, that the third and fourth satellites vanish and reappear on the same side of the disc (N. 94). These eclipses are in all respects similar to those of the moon: but, occasionally, the satellites eclipse Jupiter, sometimes passing like obscure spots across his surface, resembling annular eclipses of the sun, and sometimes like a bright spot traversing one of his dark belts. Before opposition, the shadow of the satellite, like a round black spot, precedes its passage over the disc of the planet; and after opposition, the shadow follows the satellite.

In consequence of the relations already mentioned in the mean motions and mean longitudes of the first three satellites, they never can be all eclipsed at the same time. For when the second and third are in one direction, the first is in the opposite direction; consequently, when the first is eclipsed, the other two must be between the sun and Jupiter. The instant of the beginning or end of an eclipse of a satellite marks the same instant of absolute time to all the inhabitants of the earth; therefore, the time of these eclipses observed by a traveler, when compared with the time of the eclipse computed for Greenwich, or any other fixed

meridian (N. 95), gives the difference of the meridians in time, and, consequently, the longitude of the place of observation. The eclipses of Jupiter's satellites have been the means of a discovery which, though not so immediately applicable to the wants of man, unfolds one of the properties of light—that medium without whose cheering influence all the beauties of the creation would have been to us a blank. It is observed, that those eclipses of the first satellite, which happen when Jupiter is near conjunction (N. 96), are later by 16^m $26^s\cdot6$ than those which take place when the planet is in opposition. As Jupiter is nearer to us when in opposition by the whole breadth of the earth's orbit than when in conjunction, this circumstance is attributed to the time employed by the rays of light in crossing the earth's orbit, a distance of about 190,000,000 of miles; whence it is estimated that light travels at the rate of 190,000 miles in one second. Such is its velocity, that the earth, moving at the rate of nineteen miles in a second, would take two months to pass through a distance which a ray of light would dart over in eight minutes. The subsequent discovery of the aberration of light confirmed this astonishing result.

Objects appear to be situated in the direction of the rays which proceed from them. Were light propagated instantaneously, every object, whether at rest or in motion, would appear in the direction of these rays; but as light takes some time to travel, we see Jupiter in conjunction, by means of rays that left him 16^m $26^s\cdot6$ before; but, during that time, we have changed our position, in consequence of the motion of the earth in its orbit: we therefore refer Jupiter to a place in which he is not. His true position is in the diagonal (N. 97) of the parallelogram, whose sides are in the ratio of the velocity of light to the velocity of the earth in its orbit, which is as 190,000 to 19, or 10,000 to 1. In consequence of the aberration of light, the heavenly bodies seem to be in places in which they are not. In fact, if the earth were at rest, rays from a star would pass along the axis of a telescope directed to it; but if the earth were to begin to move in its orbit, with its usual velocity, these rays would strike against the side of the tube; it

would, therefore, be necessary to incline the telescope
a little, in order to see the star. The angle contained
between the axis of the telescope and a line drawn to
the true place of the star, is its aberration, which varies
in quantity and direction in different parts of the earth's
orbit; but as it is only 20″·36, it is insensible in ordinary
cases (N. 98).

The velocity of light deduced from the observed aber-
ration of the fixed stars perfectly corresponds with that
given by the eclipses of the first satellite. The same
result, obtained from sources so different, leaves not a
doubt of its truth. Many such beautiful coincidences,
derived from circumstances apparently the most un-
promising and dissimilar, occur in physical astronomy,
and prove connections which we might otherwise be un-
able to trace. The identity of the velocity of light, at
the distance of Jupiter, and on the earth's surface, shows
that its velocity is uniform; and if light consists in the
vibrations of an elastic fluid or ether filling space, a hy-
pothesis which accords best with observed phenomena,
the uniformity of its velocity shows that the density
of the fluid throughout the whole extent of the solar
system must be proportional to its elasticity (N. 99).
Among the fortunate conjectures which have been con-
firmed by subsequent experience, that of Bacon is not
the least remarkable. "It produces in me," says the
restorer of true philosophy, "a doubt whether the face
of the serene and starry heavens be seen at the instant
it really exists, or not till some time later: and whether
there be not, with respect to the heavenly bodies, a true
time and an apparent time, no less than a true place
and an apparent place, as astronomers say, on account
of parallax. For it seems incredible that the species or
rays of the celestial bodies can pass through the im-
mense interval between them and us in an instant, or
that they do not even require some considerable portion
of time."

Great discoveries generally lead to a variety of con-
clusions: the aberration of light affords a direct proof of
the motion of the earth in its orbit; and its rotation is
proved by the theory of falling bodies, since the centri-
fugal force it induces retards the oscillations of the pen-

dulum (N. 100) in going from the pole to the equator. Thus a high degree of scientific knowledge has been requisite to dispel the errors of the senses.

The little that is known of the theories of the satellites of Saturn and Uranus, is, in all respects, similar to that of Jupiter. Saturn is accompanied by seven satellites, the most distant of which is about the size of the planet Mars. Its orbit has a sensible inclination to the plane of the ring; but the great compression of Saturn occasions the other satellites to move nearly in the plane of his equator. So many circumstances must concur to render the two interior satellites visible, that they have very rarely been seen. They move exactly at the edge of the ring, and their orbits never deviate from its plane. In 1789, Sir William Herschel saw them, like beads, threading the slender line of light which the ring is reduced to, when seen edgewise from the earth. And for a short time he perceived them advancing off it at each end, when turning round in their orbits. The eclipses of the exterior satellites only take place when the ring is in this position. Of the situation of the equator of Uranus we know nothing, nor of his compression; but the orbits of his satellites are nearly perpendicular to the plane of the ecliptic; and, by analogy, they ought to be in the plane of his equator. Uranus is so remote that he has more the appearance of a planetary nebula than a planet, which renders it extremely difficult to distinguish the satellites at all; and quite hopeless without such a telescope as is rarely to be met with even in observatories. Sir William Herschel discovered six, and determined the motions of two of them; but from that time the position of the planet has been such as to render farther observations impossible. The subject has recently occupied the attention of his son, who has found evidence of the general correctness of his father's views, and has been enabled to determine the elements of the motions of these minute objects with more accuracy. The first satellite performs its revolution about Uranus in 8^d 16^h 56^m $28^s\cdot6$; and the second satellite accomplishes its period in 13^d 11^h 7^m $12^s\cdot6$. The orbits of both seem to have an inclination of about $101°\cdot2$ to the plane of the ecliptic; and their motions offer the singu-

lar phenomenon of being retrograde, or from east to
west; while all the planets and the other satellites re-
volve in the contrary direction. Sir John Herschel could
not perceive the smallest indication of a ring.

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Section V.

Lunar Theory—Periodic Perturbations of the Moon—Equation of Center-
    Evection—Variation—Annual Equation—Direct and Indirect Action of
    Planets—The Moon's Action on the Earth disturbs her own Motion—
    Eccentricity and Inclination of Lunar Orbit Invariable—Acceleration—
    Secular Variation in Nodes and Perigee—Motion of Nodes and Perigee
    inseparably connected with the Acceleration—Nutation of Lunar Orbit
    —Form and Internal Structure of the Earth determined from it—Lunar,
    Solar, and Planetary Eclipses—Occultations and Lunar Distances—Mean
    Distance of the Sun from the Earth obtained from Lunar Theory—Abso-
    lute Distances of the Planets, how Found.

OUR constant companion, the moon, next claims our
attention. Several circumstances concur to render her
motions the most interesting, and at the same time the
most difficult to investigate, of all the bodies of our sys-
tem. In the solar system, planet troubles planet; but in
the lunar theory, the sun is the great disturbing cause;
his vast distance being compensated by his enormous
magnitude, so that the motions of the moon are more
irregular than those of the planets; and, on account of
the great ellipticity of her orbit, and the size of the sun,
the approximations to her motions are tedious and diffi-
cult, beyond what those unaccustomed to such investiga-
tions could imagine. The average distance of the moon
from the center of the earth is only 237,360 miles, so
that her motion among the stars is perceptible in a few
hours. She completes a circuit of the heavens in
27^d 7^h 43^m $4^{s.}7$, moving in an orbit whose eccentricity is
about 12,985 miles. The moon is about four hundred
times nearer to the earth than the sun. The proximity
of the moon to the earth keeps them together. For so
great is the attraction of the sun, that if the moon were
farther from the earth, she would leave it altogether, and
would revolve as an independent planet about the sun.
   The disturbing action (N. 101) of the sun on the moon
is equivalent to three forces. The first, acting in the
direction of the line joining the moon and earth, in-

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creases or diminishes her gravity to the earth. Th
second, acting in the direction of a tangent to her orbi
disturbs her motion in longitude ; and the third, actin
perpendicularly to the plane of her orbit, disturbs he
motion in latitude—that is, it brings her nearer or re
moves her farther from the plane of the ecliptic tha
she would otherwise be. The periodic perturbation
in the moon arising from these forces, are perfectly sim
ilar to the periodic perturbations of the planets. Br
they are much greater and more numerous ; becaus
the sun is so large, that many inequalities which ar
quite insensible in the motions of the planets, are c
great magnitude in those of the moon. Among the in
numerable periodic inequalities to which the moon'
motion in longitude is liable, the most remarkable are
the Equation of the Center, which is the difference be
tween the moon's mean and true longitude, the Evec
tion, the Variation, and the Annual Equation. The
disturbing force which acts in the line joining the moo
and earth produces the Evection : it diminishes the ec
centricity of the lunar orbit in conjunction and opposi
tion, thereby making it more circular, and augments i
in quadrature, which consequently renders it more ellip
tical. The period of this inequality is less than thirty
two days. Were the increase and diminution alway:
the same, the Evection would only depend upon the
distance of the moon from the sun ; but its absolute
value also varies with her distance from the perigee
(N. 102) of her orbit. Ancient astronomers, who ob-
served the moon solely with a view to the prediction of
eclipses, which can only happen in conjunction and oppo-
sition, where the eccentricity is diminished by the Evec-
tion, assigned too small a value to the ellipticity of her
orbit (N. 193). The Evection was discovered by Ptole-
my from observation, about A. D. 140. The variation
produced by the tangential disturbing force, which is
at its maximum when the moon is 45° distant from the
sun, vanishes when that distance amounts to a quadrant,
and also when the moon is in conjunction and opposi-
tion ; consequently, that inequality never could have
been discovered from the eclipses : its period is half a
lunar month (N. 104). The Annual Equation depends

upon the sun's distance from the earth : it arises from
the moon's motion being accelerated when that of the
earth is retarded, and *vice versâ*—for when the earth is
in its perihelion, the lunar orbit is enlarged by the ac-
tion of the sun; therefore, the moon requires more
time to perform her revolution.   But, as the earth ap-
proaches its aphelion, the moon's orbit contracts, and
less time is necessary to accomplish her motion—its
period, consequently, depends upon the time of the
year.   In the eclipses, the annual equation combines
with the equation of the center of the terrestrial orbit,
so that ancient astronomers imagined the earth's orbit
to have a greater eccentricity than modern astronomers
assign to it.

The planets disturb the motion of the moon both
directly and. indirectly : their action on the earth alters
its relative position with regard to the sun and moon,
and occasions inequalities in the moon's motion, which
are more considerable than those arising from their
direct action ; for the same reason the moon, by disturb-
ing the earth, indirectly disturbs her own motion. ˙ Nei-
ther the eccentricity of the lunar orbit, nor its mean
inclination to the plane of the ecliptic, have experienced
any changes from secular inequalities; for, although
the mean action of the sun on the moon depends upon
the inclination of the lunar orbit to the ecliptic, and the
position of the ecliptic is subject to a secular inequality,
yet analysis shows that it does not occasion a secular
variation in the inclination of the lunar orbit, because
the action of the sun constantly brings the moon's orbit
to the same inclination to the ecliptic.   The mean mo-
tion, the nodes, and the perigee, however, are subject
to very remarkable variations.

From the eclipse observed by the Chaldeans at Baby-
lon, on the 19th of March, seven hundred and twenty-
one years before the Christian era, the place of the
moon is known from that of the sun at the instant of
opposition (N. 83), whence her mean longitude may be
found.   But the comparison of this mean longitude with
another mean longitude, computed back for the instant
of the eclipse from modern observations, shows that the
moon performs her revolution round the earth more

rapidly and in a shorter time now than she did formerly,
and that the acceleration in her mean motion has been
increasing from age to age as the square of the time
(N. 105). All ancient and intermediate eclipses confirm
this result. As the mean motions of the planets have
no secular inequalities, this seemed to be an unaccount-
able anomaly. It was at one time attributed to the re-
sistance of an ethereal medium pervading space, and at
another to the successive transmission of the gravitating
force. But as La Place proved that neither of these
causes, even if they exist, have any influence on the
motions of the lunar perigee (N. 102) or nodes, they
could not affect the mean motion; a variation in the
mean motion from such causes being inseparably con-
nected with the variations in the motions of the perigee
and nodes. That great mathematician, in studying the
theory of Jupiter's satellites, perceived that the secular
variation in the elements of Jupiter's orbit, from the
action of the planets, occasions corresponding changes
in the motions of the satellites, which led him to sus-
pect that the acceleration in the mean motion of the
moon might be connected with the secular variation in
the eccentricity of the terrestrial orbit. Analysis has
shown that he assigned the true cause of the acceleration.

It is proved that the greater the eccentricity of the
terrestrial orbit, the greater is the disturbing action of
the sun on the moon. Now as the eccentricity has
been decreasing for ages, the effect of the sun in dis-
turbing the moon has been diminishing during that time.
Consequently the attraction of the earth has had a more
and more powerful effect on the moon, and has been
continually diminishing the size of the lunar orbit. So
that the moon's velocity has been gradually augmenting
for many centuries to balance the increase of the earth's
attraction. This secular increase in the moon's velocity
is called the Acceleration, a name peculiarly appropriate
at present, and which will continue to be so for a vast
number of ages; because, as long as the earth's eccen-
tricity diminishes, the moon's mean motion will be ac-
celerated; but when the eccentricity has passed its
minimum, and begins to increase, the mean motion will
be retarded from age to age. The secular acceleration

is now about 11″·9, but its effect on the moon's place increases as the square of the time. It is remarkable that the action of the planets, thus reflected by the sun to the moon, is much more sensible than their direct action either on the earth or moon. The secular diminution in the eccentricity, which has not altered the equation of the center of the sun by eight minutes since the earliest recorded eclipses, has produced a variation of about 1° 48′ in the moon's longitude, and of 7° 12′ in her mean anomaly (N. 106).

The action of the sun occasions a rapid but variable motion in the nodes and perigee of the lunar orbit. Though the nodes recede during the greater part of the moon's revolution, and advance during the smaller, they perform their sidereal revolution in 6793^d 9^h 23^m 9^s·3 ; and the perigee accomplishes a revolution in 3232^d 13^h 48^m 29^s·6, or a little more than nine years, notwithstanding its motion is sometimes retrograde and sometimes direct : but such is the difference between the disturbing energy of the sun and that of all the planets put together, that it requires no less than 109,830 years for the greater axis of the terrestrial orbit to do the same, moving at the rate of 11″·8 annually. The form of the earth has no sensible effect either on the lunar nodes or apsides. It is evident that the same secular variation which changes the sun's distance from the earth, and occasions the acceleration in the moon's mean motion, must affect the nodes and perigee. It consequently appears, from theory as well as observation, that both these elements are subject to a secular inequality, arising from the variation in the eccentricity of the earth's orbit, which connects them with the Acceleration, so that both are retarded when the mean motion is anticipated. The secular variations in these three elements are in the ratio of the numbers 3, 0·735, and 1 ; whence the three motions of the moon, with regard to the sun, to her perigee, and to her nodes, are continually accelerated, and their secular equations are as the numbers 1, 4·702, and 0·612. A comparison of ancient eclipses observed by the Arabs, Greeks, and Chaldeans, imperfect as they are, with modern observations, confirms these results of analysis. Future ages will de-

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velop these great inequalities, which at some most distant period will amount to many circumferences (N. 107). They are, indeed, periodic; but who shall tell their period? Millions of years must elapse before that great cycle is accomplished.

The moon is so near, that the excess of matter at the earth's equator occasions periodic variations in her longitude, and also that remarkable inequality in her latitude, already mentioned as a nutation in the lunar orbit, which diminishes its inclination to the ecliptic when the moon's ascending node coincides with the equinox of spring, and augments it when that node coincides with the equinox of autumn. As the cause must be proportional to the effect, a comparison of these inequalities, computed from theory, with the same given by observation, shows that the compression of the terrestrial spheroid, or the ratio of the difference between the polar and the equatorial diameters, to the diameter of the equator, is $\frac{1}{305 \cdot 05}$. It is proved analytically, that if a fluid mass of homogeneous matter, whose particles attract each other inversely as the squares of the distance, were to revolve about an axis as the earth does, it would assume the form of a spheroid whose compression is $\frac{1}{230}$. Since that is not the case, the earth cannot be homogeneous, but must decrease in density from its center to its circumference. Thus the moon's eclipses show the earth to be round; and her inequalities not only determine the form, but even the internal structure of our planet; results of analysis which could not have been anticipated. Similar inequalities in the motions of Jupiter's satellites prove that his mass is not homogeneous, and that his compression is $\frac{1}{13 \cdot 8}$. His equatorial diameter exceeds his polar diameter by about 6000 miles.

The phases (N. 108) of the moon, which vary from a slender silvery crescent soon after conjunction to a complete circular disc of light in opposition, decrease by the same degrees till the moon is again enveloped in the morning beams of the sun. These changes regulate the returns of the eclipses. Those of the sun can only happen in conjunction, when the moon, coming between the earth and the sun, intercepts his light. Those of

the moon are occasioned by the earth intervening be-
tween the sun and moon when in opposition. As the
earth is opaque and nearly spherical, it throws a conical
shadow on the side of the moon opposite to the sun, the
axis of which passes through the centers of the sun and
earth (N. 109). The length of the shadow terminates
at the point where the apparent diameters (N. 110)
of the sun and earth would be the same. When the
moon is in opposition, and at her mean distance, the
diameter of the sun would be seen from her center
under an angle of 1918″·1. That of the earth would
appear under an angle of 6908″·3. So that the length
of the shadow is at least three times and a half greater
than the distance of the moon from the earth, and the
breadth of the shadow, where it is traversed by the
moon, is about eight-thirds of the lunar diameter. Hence
the moon would be eclipsed every time she is in oppo-
sition, were it not for the inclination of her orbit to the
plane of the ecliptic, in consequence of which the moon
when in opposition is either above or below the cone of
the earth's shadow, except when in or near her nodes.
Her position with regard to them occasions all the vari-
eties in the lunar eclipses. Every point of the moon's
surface successively loses the light of different parts of
the sun's disc before being eclipsed. Her brightness
therefore gradually diminishes before she plunges into
the earth's shadow. The breadth of the space occupied
by the penumbra (N. 111) is equal to the apparent di-
ameter of the sun, as seen from the center of the moon.
The mean duration of a revolution of the sun, with re-
gard to the node of the lunar orbit, is to the duration of
a synodic revolution (N. 112) of the moon as 223 to 19.
So that, after a period of 223 lunar months, the sun and
moon would return to the same relative position with
regard to the node of the moon's orbit, and therefore
the eclipses would recur in the same order, were not
the periods altered by irregularities in the motions of
the sun and moon. In lunar eclipses, our atmosphere
bends the sun's rays which pass through it all round
into the cone of the earth's shadow. And as the hori-
zontal refraction (N. 113) or bending of the rays sur-
passes half the sum of the semidiameters of the sun

and moon, divided by their mutual distance, the center of the lunar disc, supposed to be in the axis of the shadow, would receive the rays from the same point of the sun, round all sides of the earth, so that it would be more illuminated than in full moon, if the greater portion of the light were not stopped or absorbed by the atmosphere. Instances are recorded where this feeble light has been entirely absorbed, so that the moon has altogether disappeared in her eclipses.

The sun is eclipsed when the moon intercepts his rays (N. 114). The moon, though incomparably smaller than the sun, is so much nearer the earth, that her apparent diameter differs but little from his, but both are liable to such variations, that they alternately surpass one another. Were the eye of a spectator in the same straight line with the centers of the sun and moon, he would see the sun eclipsed. If the apparent diameter of the moon surpassed that of the sun, the eclipse would be total. If it were less, the observer would see a ring of light round the disc of the moon, and the eclipse would be annular, as it was on the 17th of May, 1836. If the center of the moon should not be in the straight line joining the centers of the sun and the eye of the observer, the moon might only eclipse a part of the sun. The variation, therefore, in the distances of the sun and moon from the center of the earth, and of the moon from her node at the instant of conjunction, occasions great varieties in the solar eclipses. Besides, the height of the moon above the horizon changes her apparent diameter, and may augment or diminish the apparent distances of the centers of the sun and moon, so that an eclipse of the sun may occur to the inhabitants of one country, and not to those of another. In this respect the solar eclipses differ from the lunar, which are the same for every part of the earth where the moon is above the horizon. In solar eclipses, the light reflected by the atmosphere diminishes the obscurity they produce. Even in total eclipses the higher part of the atmosphere is enlightened by a part of the sun's disc, and reflects its rays to the earth. The whole disc of the new moon is frequently visible from atmospheric reflection.

A phenomenon altogether unprecedented occurred during the total eclipse of the sun which happened on the 8th of July, 1842. The moon was like a black patch on the sky surrounded by a faint whitish light about the eighth of the moon's diameter in breadth, in which three red flames appeared in form like the teeth of a saw; from what cause they originated, or what they were, is totally unknown.

Planets sometimes eclipse one another. On the 17th of May, 1737, Mercury was eclipsed by Venus near their inferior conjunction; Mars passed over Jupiter on the 9th of January, 1591; and on the 30th of October, 1825, the moon eclipsed Saturn. These phenomena, however, happen very seldom, because all the planets, or even a part of them, are very rarely seen in conjunction at once; that is, in the same part of the heavens at the same time. More than 2500 years before our era, the five great planets were in conjunction. On the 15th of September, 1186, a similar assemblage took place between the constellations of Virgo and Libra; and in 1801, the moon, Jupiter, Saturn, and Venus were united in the heart of the Lion. These conjunctions are so rare, that Lalande has computed that more than seventeen millions of millions of years separate the epochs of the contemporaneous conjunctions of the six great planets.

The motions of the moon have now become of more importance to the navigator and geographer than those of any other heavenly body, from the precision with which terrestrial longitude is determined by occultations of stars, and by lunar distances. In consequence of the retrograde motion of the nodes of the lunar orbit, at the rate of 3' 10''·64 daily, these points make a tour of the heavens in a little more than eighteen years and a half. This causes the moon to move round the earth in a kind of spiral, so that her disc at different times passes over every point in a zone of the heavens extending rather more than 5° 9' on each side of the ecliptic. It is therefore evident, that at one time or other she must eclipse every star and planet she meets with in this space. Therefore the occultation of a star by the moon is a phenomenon of frequent occurrence. The moon seems to

ity; but the other, being at a tangent to the surface, urges the particles toward the equator, where they accumulate till their numbers compensate the diminution of gravity, which makes the mass bulge at the equator, and become flattened at the poles. It appears, then, that the influence of the centrifugal force is most powerful at the equator, not only because it is actually greater there than elsewhere, but because its whole effect is employed in diminishing gravity, whereas, in every other point of the fluid mass, it is only a part that is so employed. For both these reasons, it gradually decreases toward the poles, where it ceases. On the contrary, gravity is least at the equator, because the particles are farther from the center of the mass, and increases toward the poles, where it is greatest. It is evident, therefore, that, as the centrifugal force is much less than the force of gravity—gravitation, which is the difference between the two, is least at the equator, and continually increases toward the poles, where it is a maximum. On these principles Sir Isaac Newton proved that a homogeneous fluid (N. 118) mass in rotation assumes the form of an ellipsoid of revolution (N. 119), whose compression is $\frac{1}{230}$. Such, however, cannot be the form of the earth, because the strata increase in density toward the center. The lunar inequalities also prove the earth to be so constructed; it was requisite, therefore, to consider the fluid mass to be of variable density. Including this condition, it has been found that the mass, when in rotation, would still assume the form of an ellipsoid of revolution; that the particles of equal density would arrange themselves in concentric elliptical strata (N. 120), the most dense being in the center; but that the compression or flattening would be less than in the case of the homogeneous fluid. The compression is still less when the mass is considered to be, as it actually is, a solid nucleus, decreasing regularly in density from the center to the surface, and partially covered by the ocean, because the solid parts, by their cohesion, nearly destroy that part of the centrifugal force which gives the particles a tendency to accumulate at the equator, though not altogether; otherwise the sea, by the superior mobility of its particles, would flow toward the equator and leave

the poles dry. Beside, it is well known, that the con-
tinents at the equator are more elevated than they are
in higher latitudes. It is also necessary for the equili-
brium of the ocean, that its density should be less than
the mean density of the earth, otherwise the continents
would be perpetually liable to inundations from storms,
and other causes. On the whole, it appears from the-
ory, that a horizontal line passing round the earth
through both poles, must be nearly an ellipse, having its
major axis in the plane of the equator, and its minor
axis coincident with the axis of the earth's rotation
(N. 121). It is easy to show, in a spheroid whose
strata are elliptical, that the increase in the length of
the radii (N. 122), the decrease of gravitation, and the
increase in the length of the arcs of the meridian, cor-
responding to angles of one degree, from the poles to
the equator, are all proportional to the square of the co-
sine of the latitude (N. 123). These quantities are so
connected with the ellipticity of the spheroid that the
total increase in the length of the radii is equal to the
compression or flattening, and the total diminution in the
length of the arcs is equal to the compression, multi-
plied by three times the length of an arc of one degree
at the equator. Hence, by measuring the meridian
curvature of the earth, the compression, and conse-
quently its figure, become known. This, indeed, is as-
suming the earth to be an ellipsoid of revolution, but
the actual measurement of the globe will show how far
it corresponds with that solid in figure and constitution.

The courses of the great rivers, which are in general
navigable to a considerable extent, prove that the curva-
ture of the land differs but little from that of the ocean;
and as the heights of the mountains and continents are
inconsiderable when compared with the magnitude of
the earth, its figure is understood to be determined by
a surface at every point perpendicular to the direction
of gravitation, or of the plumb-line, and is the same
which the sea would have, if it were continued all round
the earth beneath the continents. Such is the figure
that has been measured in the following manner :—

A terrestrial meridian is a line passing through both
poles, all the points of which have their noon contem-

poraneously. Were the lengths and curvatures of different meridians known, the figure of the earth might be determined. But the length of one degree is sufficient to give the figure of the earth, if it be measured on different meridians, and in a variety of latitudes. For if the earth were a sphere, all degrees would be of the same length; but if not, the lengths of the degrees would be greater, exactly in proportion as the curvature is less. A comparison of the length of a degree in different parts of the earth's surface, will therefore determine its size and form.

An arc of the meridian may be measured by observing the latitude of its extreme points (N. 124), and then measuring the distance between them in feet or fathoms. The distance thus determined on the surface of the earth, divided by the degrees and parts of a degree contained in the difference of the latitudes, will give the exact length of one degree, the difference of the latitudes being the angle contained between the verticals at the extremities of the arc. This would be easily accomplished were the distance unobstructed, and on a level with the sea. But, on account of the innumerable obstacles on the surface of the earth, it is necessary to connect the extreme points of the arc by a series of triangles (N. 125), the sides and angles of which are either measured or computed, so that the length of the arc is ascertained with much laborious calculation. In consequence of the irregularities of the surface, each triangle is in a different plane. They must therefore be reduced by computation to what they would have been had they been measured on the surface of the sea. And as the earth may in this case be esteemed spherical, they require a correction to reduce them to spherical triangles. The gentlemen who conducted the trigonometrical survey, in measuring 500 feet of a base in Ireland twice over, found that the difference in the two measurements did not amount to the 800th part of an inch. Such is the accuracy with which these operations are conducted, and which they require.

Arcs of the meridian have been measured in a variety of latitudes north and south, as well as arcs perpendicular to the meridian. From these measurements it ap-

pears that the length of the degrees increases from the equator to the poles, nearly in proportion to the square of the sine of the latitude (N. 126). Consequently, the convexity of the earth diminishes from the equator to the poles.

Were the earth an ellipsoid of revolution, the meridians would be ellipses whose lesser axes would coincide with the axis of rotation, and all the degrees measured between the pole and the equator would give the same compression when combined two and two. That, however, is far from being the case. Scarcely any of the measurements give exactly the same results, chiefly on account of local attractions, which cause the plumb line to deviate from the vertical. The vicinity of mountains has that effect. But one of the most remarkable, though not unprecedented, anomalies takes place in the plains of the north of Italy, where the action of some dense subterraneous matter causes the plumb-line to deviate seven or eight times more than it did from the attraction of Chimborazo, in the experiments of Bouguer, while measuring a degree of the meridian at the equator. In consequence of this local attraction, the degrees of the meridian in that part of Italy seem to increase toward the equator through a small space, instead of decreasing, as if the earth was drawn out at the poles, instead of being flattened.

Many other discrepancies occur, but from the mean of the five principal measurements of arcs in Peru, India, France, England, and Lapland, Mr. Ivory has deduced that the figure which most nearly follows this law is an ellipsoid of revolution whose equatorial radius is 3962·824 miles, and the polar radius 3949·585 miles. The difference, or 13·239 miles, divided by the equatorial radius, is $\frac{1}{299}$ nearly. This fraction is called the compression of the earth, and does not differ much from that given by the lunar inequalities. If we assume the earth to be a sphere, the length of a degree of the meridian is $69\frac{1}{2\frac{1}{2}}$ British miles. Therefore 360 degrees, or the whole circumference of the globe, is 24,856 miles, and the diameter, which is something less than a third of the circumference, is about 7916, or 8000 miles nearly. Eratosthenes, who died 194 years before the Christian

era, was the first to give an approximate value of the
earth's circumference, by the measurement of an arc
between Alexandria and Syene.

There is another method of finding the figure of the
earth, totally different from the preceding, solely depend-
ing upon the increase of gravitation from the equator to
the poles. The force of gravitation at any place is
measured by the descent of a heavy body during the first
second of its fall. And the intensity of the centrifugal
force is measured by the deflection of any point from the
tangent in a second. For, since the centrifugal force bal-
ances the attraction of the earth, it is an exact measure of
the gravitating force. Were the attraction to cease, a body
on the surface of the earth would fly off in the tangent
by the centrifugal force, instead of bending round in the
circle of rotation. Therefore, the deflection of the cir-
cle from the tangent in a second measures the intensity
of the earth's attraction, and is equal to the versed sine
of the arc described during that time, a quantity easily
determined from the known velocity of the earth's rota-
tion. Whence it has been found, that at the equator
the centrifugal force is equal to the 289th part of gravity.
Now, it is proved by analysis that whatever the consti-
tution of the earth and planets may be, if the intensity
of gravitation at the equator be taken equal to unity, the
sum of the compression of the ellipsoid, and the whole
increase of gravitation from the equator to the pole, is
equal to five halves of the ratio of the centrifugal force
to gravitation at the equator. This quantity with regard
to the earth is $\frac{5}{2}$ of $\frac{1}{289}$, or $\frac{1}{115.3}$. Consequently, the
compression of the earth is equal to $\frac{1}{115.3}$ diminished by
the whole increase of gravitation. So that its form will
be known, if the whole increase of gravitation from the
equator to the pole can be determined by experiment.
This has been accomplished by a method founded upon
the following considerations:—If the earth were a homo-
geneous sphere without rotation, its attraction on bodies
at its surface would be everywhere the same. If it
be elliptical and of variable density, the force of gravity,
theoretically, ought to increase from the equator to the
pole, as unity *plus* a constant quantity multiplied into the
square of the sine of the latitude (N. 126). But for a

spheroid in rotation, the centrifugal force varies, by the laws of mechanics, as the square of the sine of the latitude, from the equator, where it is greatest, to the pole, where it vanishes. And as it tends to make bodies fly off the surface, it diminishes the force of gravity by a small quantity. Hence, by gravitation, which is the difference of these two forces, the fall of bodies ought to be accelerated from the equator to the poles proportionably to the square of the sine of the latitude; and the weight of the same body ought to increase in that ratio. This is directly proved by the oscillations of the pendulum (N. 127), which, in fact, is a falling body; for if the fall of bodies be accelerated, the oscillations will be more rapid: in order, therefore, that they may always be performed in the same time, the length of the pendulum must be altered. By numerous and careful experiments, it is proved that a pendulum which oscillates 86,400 times in a mean day at the equator, will do the same at every point of the earth's surface, if its length be increased progressively to the pole, as the square of the sine of the latitude.

From the mean of these it appears that the whole decrease of gravitation from the poles to the equator is 0·005.1449, which, subtracted from $\frac{1}{115.5}$, shows that the compression of the terrestrial spheroid is about $\frac{1}{285.26}$. This value has been deduced by the late Mr. Baily, president of the Astronomical Society, who has devoted much attention to this subject; at the same time, it may be observed that no two sets of pendulum experiments give the same result, probably from local attractions. Therefore, the question cannot be considered as definitively settled, though the differences are very small. The compression obtained by this method does not differ much from that given by the lunar inequalities, nor from the arcs in the direction of the meridian, and those perpendicular to it. The near coincidence of these three values, deduced by methods so entirely independent of each other, shows that the mutual tendencies of the centers of the celestial bodies to one another and the attraction of the earth for bodies at its surface result from the reciprocal attraction of all their particles. Another proof may be added. The

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nutation of the earth's axis and the precession of the
equinoxes (N. 143) are occasioned by the action of the
sun and moon on the protuberant matter at the earth's
equator. And although these inequalities do not give
the absolute value of the terrestrial compression, they
show that the fraction expressing it is comprised be-
tween the limits $\frac{1}{279}$ and $\frac{1}{573}$.

It might be expected that the same compression
should result from each, if the different methods of ob-
servation could be made without error. This, however,
is not the case; for, after allowance has been made for
every cause of error, such discrepancies are found, both
in the degrees of the meridian and in the length of the
pendulum, as show that the figure of the earth is very
complicated. But they are so small, when compared
with the general results, that they may be disregarded.
The compression deduced from the mean of the whole
appears not to differ much from $\frac{1}{300}$; that given by the
lunar theory has the advantage of being independent of
the irregularities of the earth's surface and of local at-
tractions. The regularity with which the observed
variation in the length of the pendulum follows the law
of the square of the sine of the latitude, proves the
strata to be elliptical, and symmetrically disposed round
the center of gravity of the earth, which affords a strong
presumption in favor of its original fluidity. It is re-
markable how little influence the sea has on the varia-
tion of the lengths of the arcs of the meridian, or on
gravitation; neither does it much affect the lunar ine-
qualities, from its density being only about a fifth of the
mean density of the earth. For, if the earth were to
become a fluid, after being stripped of the ocean, it
would assume the form of an ellipsoid of revolution
whose compression is $\frac{1}{304.8}$, which differs very little
from that determined by observation, and proves, not
only that the density of the ocean is inconsiderable, but
that its mean depth is very small. There may be pro-
found cavities in the bottom of the sea, but its mean
depth probably does not much exceed the mean height
of the continents and islands above its level. On this
account, immense tracts of land may be deserted or
overwhelmed by the ocean, as appears really to have

been the case, without any great change in the form of
the terrestrial spheroid.   The variation in the length of
the pendulum was first remarked by Richter in 1672,
while observing transits of the fixed stars across the
meridian at Cayenne, about five degrees north of the
equator.   He found that his clock lost at the rate of
2^m 28^s daily, which induced him to determine the
length of a pendulum beating seconds in that latitude;
and repeating the experiments on his return to Europe,
he found the seconds' pendulum at Paris to be more
than the twelfth of an inch longer than that at Cayenne.
The form and size of the earth being determined,
a standard of measure is furnished with which the di-
mensions of the solar system may be compared.

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Section VII.

THE parallax of a celestial body is the angle under
which the radius of the earth would be seen, if viewed
from the center of that body; it affords the means of
ascertaining the distances of the sun, moon, and planets
(N. 128).   When the moon is in the horizon at the
instant of rising or setting, suppose lines to be drawn
from her center to the spectator and to the center of the
earth; these would form a right-angled triangle with
the terrestrial radius, which is of a known length; and
as the parallax or angle at the moon can be measured,
all the angles and one side are given; whence the
distance of the moon from the center of the earth may
be computed.   The parallax of an object may be found,
if two observers under the same meridian, but at a very
great distance from one another, observe its zenith
distances on the same day at the time of its passage
over the meridian.   By such contemporaneous obser-
vations at the Cape of Good Hope and at Berlin, the
mean horizontal parallax of the moon was found to be
3459″, whence the mean distance of the moon is about
sixty times the mean terrestrial radius, or 237,360 miles

nearly. Since the parallax is equal to the radius of the earth divided by the distance of the moon, it varies with the distance of the moon from the earth under the same parallel of latitude, and proves the ellipticity of the lunar orbit. When the moon is at her mean distance, it varies with the terrestrial radii, thus showing that the earth is not a sphere (N. 129).

Although the method described is sufficiently accurate for finding the parallax of an object as near as the moon, it will not answer for the sun, which is so remote that the smallest error in observation would lead to a false result. But that difficulty is obviated by the transits of Venus. When that planet is in her nodes (N. 130), or within $1\frac{1}{4}°$ of them, that is, in, or nearly in, the plane of the ecliptic, she is occasionally seen to pass over the sun like a black spot. If we could imagine that the sun and Venus had no parallax, the line described by the planet on his disc, and the duration of the transit, would be the same to all the inhabitants of the earth. But as the semi-diameter of the earth has a sensible magnitude when viewed from the center of the sun, the line described by the planet in its passage over his disc appears to be nearer to his center, or farther from it, according to the position of the observer; so that the duration of the transit varies with the different points of the earth's surface at which it is observed (N. 131). This difference of time, being entirely the effect of parallax, furnishes the means of computing it from the known motions of the earth and Venus, by the same method as for the eclipses of the sun. In fact, the ratio of the distances of Venus and the sun from the earth at the time of the transit are known from the theory of their elliptical motion. Consequently the ratio of the parallaxes of these two bodies being inversely as their distances, is given; and as the transit gives the difference of the parallaxes, that of the sun is obtained. In 1769. the parallax of the sun was determined by observations of a transit of Venus made at Wardhus in Lapland, and at Otaheite in the South Sea. The latter observation was the object of Cook's first voyage. The transit lasted about six hours at Otaheite, and the difference in duration at these two stations was eight minutes; whence

the sun's horizontal parallax was found to be 8″·72.
But by other considerations it has been reduced by
Professor Encke to 8″·5776; from which the mean
distance of the sun appears to be about ninety-five mil-
lions of miles.   This is confirmed by an inequality in the
motion of the moon, which depends upon the parallax of
the sun, and which, when compared with observation,
gives 8″·6 for the sun's parallax.

The parallax of Venus is determined by her transits;
that of Mars by direct observation, and it is found to be
nearly double that of the sun, when the planet is in
opposition.   The distance of these two planets from
the earth is therefore known in terrestrial radii, conse-
quently their mean distances from the sun may be
computed; and as the ratios of the distances of the
planets from the sun are known by Kepler's law, of the
squares of the periodic times of any two planets being
as the cubes of their mean distances from the sun, their
absolute distances in miles are easily found (N. 132).
This law is very remarkable, in thus uniting all the
bodies of the system, and extending to the satellites as
well as the planets.

Far as the earth seems to be from the sun, Uranus is
no less than nineteen times farther.   Situate on the
verge of the system, the sun must appear to it not
much larger than Venus does to us.   The earth cannot
even be visible as a telescopic object to a body so re-
mote.   Yet man, the inhabitant of the earth, soars
beyond the vast dimensions of the system to which his
planet belongs, and assumes the diameter of its orbit
as the base of a triangle whose apex extends to the
stars.

Sublime as the idea is, this assumption proves in-
effectual, except in a very few cases; for the apparent
places of the fixed stars are not sensibly changed by the
earth's annual revolution.   With the aid derived from
the refinements of modern astronomy, and of the most
perfect instruments, a sensible parallax has been de-
tected only in a very few of these remote suns.   a Cen-
tauri has a parallax of one second of space, therefore it
is the nearest known star, and yet it is more than two
hundred thousand times farther from us than the sun

is. At such a distance not only the terrestrial orbit
shrinks to a point, but the whole solar system, seen in
the focus of the most powerful telescope, might be
eclipsed by the thickness of a spider's thread. Light,
flying at the rate of 190,000 miles in a second, would
take more than three years to travel over that space.
One of the nearest stars may therefore have been
kindled or extinguished more than three years, before
we could have been aware of so mighty an event. But
this distance must be small, when compared with that
of the most remote of the bodies which are visible in
the heavens. The fixed stars are undoubtedly luminous
like the sun; it is therefore probable that they are not
nearer to one another than the sun is to the nearest of
them. In the milky way and the other starry nebulæ,
some of the stars that seem to us to be close to others,
may be far behind them in the boundless depths of
space; nay, may be rationally supposed to be situate
many thousand times farther off. Light would there-
fore require thousands of years to come to the earth
from those myriads of suns of which our own is but
"the remote companion."

SECTION VIII.

Masses of Planets that have no Satellites determined from their Perturba-
  tions—Masses of the others obtained from the Motions of their Satellites
  —Masses of the Sun, the Earth, of Jupiter, and of the Jovial System—
  Mass of the Moon—Real Diameters of Planets, how obtained—Size of
  Sun—Densities of the Heavenly Bodies—Formation of Astronomical
  Tables—Requisite Data and Means of obtaining them.

THE masses of such planets as have no satellites, are
known by comparing the inequalities they produce in
the motions of the earth and of each other, determined
theoretically, with the same inequalities given by ob-
servation; for the disturbing cause must necessarily
be proportional to the effect it produces. The masses
of the satellites themselves may also be compared with
that of the sun by their perturbations. Thus, it is
found, from the comparison of a vast number of observa-
tions, with La Place's theory of Jupiter's satellites,

that the mass of the sun is no less than 65,000,000
times greater than the least of these moons. But as
the quantities of matter in any two primary planets are
directly as the cubes of the mean distances at which
their satellites revolve, and inversely as the squares of
their periodic times (N. 133), the mass of the sun and
of any planets which have satellites may be compared
with the mass of the earth. In this manner it is com-
puted that the mass of the sun is 354,936 times that
of the earth; whence the great perturbations of the
moon, and the rapid motion of the perigee and nodes of
her orbit (N. 134). Even Jupiter, the largest of the
planets, has recently been found by Professor Airy to
be 1048·7 times less than the sun; and, indeed, the
mass of the whole Jovial System is not more than the
1046·77th part of that of the sun. So that the mass of
the satellites bears a very small proportion to that of
their primary. The mass of the moon is determined
from several sources—from her action on the terres-
trial equator, which occasions the nutation in the axis of
rotation; from her horizontal parallax; from an in-
equality she produces in the sun's longitude; and from
her action on the tides. The three first quantities,
computed from theory and compared with their ob-
served values, give her mass respectively equal to the
$\frac{1}{71}$, $\frac{1}{74.2}$, and, $\frac{1}{80.2}$ part of that of the earth, which do
not differ much from each other. Dr. Brinkley, Bishop
of Cloyne, has found it to be $\frac{1}{80}$ from the constant of
lunar nutation; but from the moon's action in raising
the tides, her mass appears to be about the $\frac{1}{75}$ part of
that of the earth—a value that cannot differ much from
the truth.

    The apparent diameters of the sun, moon, and planets
are determined by measurement; therefore, their real
diameters may be compared with that of the earth; for
the real diameter of a planet is to the real diameter of
the earth, or 7916 miles, as the apparent diameter of
the planet to the apparent diameter of the earth as seen
from the planet, that is, to twice the parallax of the
planet. According to Professor Bessel, the mean ap-
parent diameter of the sun is 1922″, and with the solar
parallax 8″·5776, it will be found that the diameter of

the sun is about 886,877 miles. Therefore, if the cen-
ter of the sun were to coincide with the center of the
earth, his volume would not only include the orbit of
the moon, but would extend nearly as far again; for
the moon's mean distance from the earth is about sixty
times the earth's mean radius, or 237,360 miles: so that
twice the distance of the moon is 474,720 miles, which
differs but little from the solar radius; his equatorial
radius is probably not much less than the major axis of
the lunar orbit.   The diameter of the moon is only 2160
miles; and Jupiter's diameter of 87,000 miles is very
much less than that of the sun; the diameter of Pallas
does not much exceed 79 miles, so that an inhabitant of
that planet, in one of our steam carriages, might go
round his world in a few hours.

The densities of bodies are proportional to their
masses, divided by their volumes. Hence, if the sun
and planets be assumed to be spheres, their volumes
will be as the cubes of their diameters. Now, the ap-
parent diameters of the sun and earth, at their mean
distance, are 1922$''$ and 17$''$·1552, and the mass of the
earth is the 354,936th part of that of the sun taken as
the unit. It follows, therefore, that the earth is nearly
four times as dense as the sun. But the sun is so large,
that his attractive force would cause bodies to fall
through about 334·65 feet in a second. Consequently,
if he were habitable by human beings, they would be
unable to move, since their weight would be thirty times
as great as it is here. A man of moderate size would
weigh about two tons at the surface of the sun; where-
as at the surface of the four new planets he would be so
light, that it would be impossible to stand steady, since
he would only weigh a few pounds. The mean density
of the earth has been recently determined with a de-
gree of accuracy that leaves nothing farther to be de-
sired. Since a comparison of the action of two planets
upon a third gives the ratio of the masses of these two
planets, it is clear that if we can compare the effect of
the whole earth with the effect of any part of it, a com-
parison may be instituted between the mass of the
whole earth and the mass of that part of it. Now a
leaden ball was weighed against the earth by comparing

the effects of each upon a pendulum; the nearness of
the smaller mass making it produce a sensible effect as
compared with that of the larger: for by the laws of
attraction the whole earth must be considered as col-
lected in its center. By this method it has been found
that the mean density of the earth is 5·675 times greater
than that of water at the temperature of 62° of Fahren-
heit's thermometer. The late Mr. Baily, whose accu-
racy as an experimental philosopher is acknowledged,
was unremittingly occupied nearly four years in accom-
plishing this very important object. All the planets and
satellites appear to be of less density than the earth.
The motion of Jupiter's satellites show that his density
increases toward his center. Were his mass homogene-
ous, his equatorial and polar axis would be in the ratio
of 41 to 36, whereas they are observed to be only as 41
to 38. The singular irregularities in the form of Sat-
urn, and the great compression of Mars, prove the in-
ternal structure of these two planets to be very far from
uniform.

Before entering on the theory of rotation, it may not
be foreign to the subject to give some idea of the meth-
ods of computing the places of the planets, and of form-
ing astronomical tables. Astronomy is now divided into
the three distinct departments of theory, observation,
and computation. Since the problem of the three bod-
ies can only be solved by approximation, the analytical
astronomer determines the position of a planet in space
by a series of corrections. Its place in its circular orbit
is first found, then the addition or subtraction of the
equation of the center (N. 48) to or from its mean place,
gives its position in the ellipse. This again is corrected
by the application of the principal periodic inequalities.
But as these are determined for some particular position
of the three bodies, they require to be corrected to suit
other relative positions. This process is continued till
the corrections become less than the errors of observa-
tion, when it is obviously unnecessary to carry the ap-
proximation further. The true latitude and distance of
the planet from the sun are obtained by methods similar
to those employed for the longitude.

As the earth revolves equably about its axis in 24

hours, at the rate of 15° in an hour, time becomes a measure of angular motion and the principal element in astronomy, where the object is to determine the exact state of the heavens, and the successive changes it undergoes in all ages, past, present, and to come. Now the longitude, latitude, and distance of a planet from the sun, are given in terms of the time, by general analytical formulæ. These formulæ will consequently give the exact place of the body in the heavens, for any time assumed at pleasure, provided they can be reduced to numbers. But before the calculator begins his task, the observer must furnish the necessary data, which are, obviously, the forms of the orbits, and their positions with regard to the plane of the ecliptic (N. 57). It is therefore necessary to determine by observation for each planet, the length of the major axis of its orbit, the eccentricity, the inclination of the orbit to the plane of the ecliptic, the longitudes of its perihelion and ascending node at a given time, the periodic time of the planet, and its longitude at any instant arbitrarily assumed, as an origin from whence all its subsequent and antecedent longitudes are estimated. Each of these quantities is determined from that position of the planet on which it has most influence. For example, the sum of the greatest and least distances of the planet from the sun is equal to the major axis of the orbit, and their difference is equal to twice the eccentricity. The longitude of the planet, when at its least distance from the sun, is the same with the longitude of the perihelion; the greatest latitude of the planet is equal to the inclination of the orbit; the longitude of the planet, when in the plane of the ecliptic in passing toward the north, is the longitude of the ascending node, and the periodic time is the interval between two consecutive passages of the planet through the same node, a small correction being made for the precession of the node, during the revolution of the planet (N. 135). Notwithstanding the excellence of instruments and the accuracy of modern observers, unavoidable errors of observation can only be compensated by finding the value of each element from the mean of a thousand, or even many thousands of observations. For as it is probable that the errors are not all in one

direction, but that some are in excess and others in defect, they will compensate each other when combined.

However, the values of the elements determined separately, can only be regarded as approximate, because they are so connected, that the estimation of any one independently, will induce errors in the others. The eccentricity depends upon the longitude of the perihelion, the mean motion depends upon the major axis, the longitude of the node upon the inclination of the orbit, and *vice versâ*. Consequently, the place of a planet computed with the approximate data will differ from its observed place. Then the difficulty is to ascertain what elements are most in fault, since the difference in question is the error of all; that is obviated by finding the errors of some thousands of observations, and combining them, so as to correct the elements simultaneously, and to make the sum of the squares of the errors a minimum with regard to each element (N. 136). The method of accomplishing this depends upon the Theory of Probabilities; a subject fertile in most important results in the various departments of science and of civil life, and quite indispensable in the determination of astronomical data. A series of observations continued for some years will give approximate values of the secular and periodic inequalities, which must be corrected from time to time, till theory and observation agree. And these again will give values of the masses of the bodies forming the solar system, which are important data in computing their motions. The periodic inequalities derived from a great number of observations are employed for the determination of the values of the masses till such time as the secular inequalities shall be perfectly known, which will then give them with all the necessary precision. When all these quantities are determined in numbers, the longitude, latitude, and distance of the planet from the sun are computed for stated intervals, and formed into tables, arranged according to the time estimated from a given epoch, so that the place of the body may be determined from them by inspection alone, at any instant, for perhaps a thousand years before and after that epoch. By this tedious process, tables have been computed for eleven planets, besides the moon and the satellites of

Section X.

Rotation of the Earth invariable—Decrease in the Earth's Mean Tempera-
ture—Earth originally in a State of Fusion—Length of Day constant—
Decrease of Temperature ascribed by Sir John Herschel to the Variation
in the Eccentricity of the Terrestrial Orbit—Difference in the Tempera-
ture of the Two Hemispheres, erroneously ascribed to the Excess in the
Length of Spring and Summer in the Southern Hemisphere ; attributed
by Mr. Lyell to the Operation of existing Causes—Three Principal Axes
of Rotation—Position of the Axis of Rotation on the Surface of the Earth
invariable—Ocean not sufficient to restore the Equilibrium of the Earth
if deranged—Its Density and Mean Depth—Internal Structure of the
Earth.

THE rotation of the earth, which determines the length
of the day, may be regarded as one of the most import-
ant elements in the system of the world. It serves as
a measure of time, and forms the standard of com-
parison for the revolutions of the celestial bodies, which
by their proportional increase or decrease would soon
disclose any changes it might sustain. Theory and
observation concur in proving that among the innumer-
able vicissitudes which prevail throughout creation, the
period of the earth's diurnal rotation is immutable.
The water of rivers, falling from a higher to a lower
level, carries with it the velocity due to its revolution
with the earth at a greater distance from the center ; it
will therefore accelerate, although to an almost infinites-
imal extent, the earth's daily rotation. The sum of all
these increments of velocity arising from the descent of
all the rivers on the earth's surface would in time be-
come perceptible, did not nature by the process of evap-
oration raise the waters back to their sources ; and thus,
by again removing matter to a greater distance from
the center, destroy the velocity generated by its pre-
vious approach ; so that the descent of rivers does not
affect the earth's rotation. Enormous masses projected
by volcanos from the equator to the poles, and the con-
trary, would indeed affect it, but there is no evidence of
such convulsions. The disturbing action of the moon
and planets, which has so powerful an effect on the
revolution of the earth, in no way influences its rota-
tion. The constant friction of the trade-winds on the

mountains and continents between the tropics does not impede its velocity, which theory even proves to be the same as if the sea together with the earth formed one solid mass. But although these circumstances be insufficient, a variation in the mean temperature would certainly occasion a corresponding change in the velocity of rotation. In the science of dynamics it is a principle in a system of bodies or of particles revolving about a fixed center, that the momentum or sum of the products of the mass of each into its angular velocity and distance from the center is a constant quantity, if the system be not deranged by a foreign cause. Now since the number of particles in the system is the same whatever its temperature may be, when their distances from the center are diminished their angular velocity must be increased, in order that the preceding quantity may still remain constant. It follows then that as the primitive momentum of rotation with which the earth was projected into space must necessarily remain the same, the smallest decrease in heat by contracting the terrestrial spheroid would accelerate its rotation, and consequently diminish the length of the day. Notwithstanding the constant accession of heat from the sun's rays, geologists have been induced to believe from the fossil remains, that the mean temperature of the globe is decreasing.

The high temperature of mines, hot springs, and above all the internal fires which have produced and do still occasion such devastation on our planet, indicate an augmentation of heat toward its center. The increase of density corresponding to the depth and the form of the spheroid being what theory assigns to a fluid mass in rotation, concurs to induce the idea that the temperature of the earth was originally so high as to reduce all the substances of which it is composed to a state of fusion or of vapor, and that in the course of ages it has cooled down to its present state; that it is still becoming colder, and that it will continue to do so till the whole mass arrives at the temperature of the medium in which it is placed, or rather at a state of equilibrium between this temperature, the cooling power of its own radiation, and the heating effect of the sun's rays.

Previous to the formation of ice at the poles, the ancient lands of northern latitudes might no doubt have been capable of producing those tropical plants preserved in the coal-measures, if indeed such plants could flourish without the intense light of a tropical sun. But even if the decreasing temperature of the earth be sufficient to produce the observed effects, it must be extremely slow in its operation; for in consequence of the rotation of the earth being a measure of the periods of the celestial motions, it has been proved that if the length of the day had decreased by the three-thousandth part of a second since the observations of Hipparchus two thousand years ago, it would have diminished the secular equation of the moon by 4″·4. It is therefore beyond a doubt that the mean temperature of the earth cannot have sensibly varied during that time. If then the appearances exhibited by the strata are really owing to a decrease of internal temperature, it either shows the immense periods requisite to produce geological changes, to which two thousand years are as nothing, or that the mean temperature of the earth had arrived at a state of equilibrium before these observations.

However strong the indications of the primitive fluidity of the earth, as there is no direct proof of it, the hypothesis can only be regarded as very probable. But one of the most profound philosophers and elegant writers of modern times has found in the secular variation of the eccentricity of the terrestrial orbit an evident cause of decreasing temperature. That accomplished author, in pointing out the mutual dependencies of phenomena, says, " It is evident that the mean temperature of the whole surface of the globe, in so far as it is maintained by the action of the sun at a higher degree than it would have were the sun extinguished, must depend on the mean quantity of the sun's rays which it receives, or—which comes to the same thing—on the total quantity received in a given invariable time; and the length of the year being unchangeable in all the fluctuations of the planetary system, it follows that the total amount of solar radiation will determine, cæteris paribus, the general

not difficult to show that this amount is inversely proportional to the minor axis of the ellipse described by the earth about the sun (N. 140), regarded as slowly variable; and that, therefore, the major axis remaining, as we know it to be constant, and the orbit being actually in a state of approach to a circle, and consequently the minor axis being on the increase, the mean annual amount of solar radiation received by the whole earth must be actually on the decrease. We have therefore an evident real cause to account for the phenomenon." The limits of the variation in the eccentricity of the earth's orbit are unknown. But if its ellipticity has ever been as great as that of the orbit of Mercury or Pallas, the mean temperature of the earth must have been sensibly higher than it is at present. Whether it was great enough to render our northern climates fit for the production of tropical plants, and for the residence of the elephant and other animals now inhabitants of the torrid zone, it is impossible to say.

Of the decrease in temperature of the northern hemisphere there is abundant evidence in the fossil plants discovered in very high latitudes, which could only have existed in a tropical climate, and which must have grown near the spot where they are found, from the delicacy of their structure and the perfect state of their preservation. This change of temperature has been erroneously ascribed to an excess in the duration of spring and summer in the northern hemisphere, in consequence of the eccentricity of the solar ellipse. The length of the seasons varies with the position of the perihelion (N. 64) of the earth's orbit for two reasons. On account of the eccentricity, small as it is, any line passing through the center of the sun divides the terrestrial ellipse into two unequal parts, and by the laws of elliptical motion the earth moves through these two portions with unequal velocities. The perihelion always lies in the smaller portion, and there the earth's motion is the most rapid. In the present position of the perihelion, spring and summer north of the equator exceed by about eight days the duration of the same seasons south of it. And 10,492 years ago the southern hemisphere enjoyed the advantage we now possess

from the secular variation of the perihelion. Yet Sir
John Herschel has shown that by this alteration neither
hemisphere acquires any excess of light or heat above
the other ; for although the earth is nearer to the sun
while moving through that part of its orbit in which the
perihelion lies than in the other part, and consequently
receives a greater quantity of light and heat, yet as it
moves faster it is exposed to the heat for a shorter
time.   In the other part of the orbit, on the contrary,
the earth being farther from the sun receives fewer of
his rays, but because its motion is slower it is exposed
to them for a longer time.   And as in both cases the
quantity of heat and the angular velocity vary exactly in
the same proportion, a perfect compensation takes place
(N. 141).   So that the eccentricity of the earth's orbit
has little or no effect on the temperature corresponding
to the difference of the seasons.

Mr. Lyell, in his excellent work on Geology, refers
the increased cold of the northern hemisphere to the
operation of existing causes, with more probability than
most theories that have been advanced in solution of
this difficult subject.   The loftiest mountains would be
represented by a grain of sand on a globe six feet in
diameter, and the depth of the ocean by a scratch on
its surface.   Consequently the gradual elevation of a
continent or chain of mountains above the surface of the
ocean, or their depression below it, is no very great
event compared with the magnitude of the earth, and
the energy of its subterranean fires, if the same periods
of time be admitted in the progress of geological as in
astronomical phenomena, which the successive and va-
rious races of extinct beings show to have been immense.
Climate is always more intense in the interior of con-
tinents than in islands or sea-coasts.   An increase of
land within the tropics would therefore augment the
general heat, and an increase in the temperate and
frigid zones would render the cold more severe.   Now
it appears that most of the European, North Asiatic,
and North American continents and islands were raised
from the deep after the coal-measures were formed in
which the fossil tropical plants are found ; and a variety
of geological facts indicate the existence of an ancient

and extensive archipelago throughout the greater part
of the northern hemisphere.   Mr. Lyell is therefore of
opinion that the climate of these islands must have
been sufficiently mild in consequence of the surrounding
ocean to clothe them with tropical plants, and render
them a fit abode for the huge animals whose fossil
remains are so often found.   That the arborescent ferns
and the palms of these regions, carried by streams to
the bottom of the ocean, were imbedded in the strata
which were by degrees heaved up by the subterranean
fires during a long succession of ages, till the greater
part of the northern hemisphere became dry land as it
now is, and that the consequence has been a continual
decrease of temperature.

It is evident from the marine shells found on the tops
of the highest mountains and in almost every part of
the globe, that immense continents have been elevated
above the ocean, which must have ingulfed others.
Such a catastrophe would be occasioned by a variation
in the position of the axis of rotation on the surface of
the earth ; for the seas tending to a new equator would
leave some portions of the globe and overwhelm others.
Now, it is found by the laws of mechanics that in every
body, be its form or density what it may, there are at
least three axes at right angles to each other, round
any one of which, if the solid begins to rotate, it will
continue to revolve forever, provided it be not disturbed
by a foreign cause, but that the rotation about any
other axis will only be for an instant, and consequently
the poles or extremities of the instantaneous axis of
rotation would perpetually change their position on the
surface of the body.   In an ellipsoid of revolution the
polar diameter and every diameter in the plane of the
equator are the only permanent axes of rotation (N.
142).   Hence if the ellipsoid were to begin to revolve
about any diameter between the pole and the equator,
the motion would be so unstable that the axis of rota-
tion and the position of the poles would change every
instant.   Therefore as the earth does not differ much
from this figure, if it did not turn round one of its prin-
cipal axes, the position of the poles would change daily ;
the equator, which is 90° distant, would undergo cor-

the experiments of Mr. Perkins they appear to be capable of a greater degree of compression than has generally been imagined.

But a density so extreme is not borne out by astronomical observation. It might seem to follow, therefore, that our planet must have a widely cavernous structure, and that we tread on a crust or shell whose thickness bears a very small proportion to the diameter of its sphere. Possibly, too, this great condensation at the central regions may be counterbalanced by the increased elasticity due to a very elevated temperature.

Section XI.

Precession and Nutation—Their Effects on the Apparent Places of the Fixed Stars.

It has been shown that the axis of rotation is invariable on the surface of the earth; and observation as well as theory prove that were it not for the action of the sun and moon on the matter at the equator, it would remain exactly parallel to itself in every point of its orbit.

The attraction of an external body not only draws a spheroid toward it, but as the force varies inversely as the square of the distance, it gives it a motion about its center of gravity, unless when the attracting body is situated in the prolongation of one of the axes of the spheroid. The plane of the equator is inclined to the plane of the ecliptic at an angle of 23° 27′ 34″·69; and the inclination of the lunar orbit to the same is 5° 8′ 47″·9. Consequently, from the oblate figure of the earth, the sun and moon acting obliquely and unequally on the different parts of the terrestrial spheroid, urge the plane of the equator from its direction and force it to move from east to west, so that the equinoctial points have a slow retrograde motion on the plane of the ecliptic, of 50″·41 annually. The direct tendency of this action is to make the planes of the equator and ecliptic coincide, but it is balanced by the tendency of the earth to return to stable rotation about the polar diameter, which is one of its principal axes of rotation. Therefore the inclina-

tion of the two planes remains constant, as a top spin-
ning preserves the same inclination to the plane of the
horizon.   Were the earth spherical, this effect would
not be produced, and the equinoxes would always cor-
respond with the same points of the ecliptic, at least as
far as this kind of motion is concerned.   But another
and totally different cause which operates on this motion
has already been mentioned.   The action of the planets
on one another and on the sun occasions a very slow va-
riation in the position of the plane of the ecliptic, which
affects its inclination to the plane of the equator, and
gives the equinoctial points a slow but direct motion on
the ecliptic of 0″·31 annually, which is entirely inde-
pendent of the figure of the earth, and would be the
same if it were a sphere.   Thus the sun and moon, by
moving the plane of the equator, cause the equinoctial
points to retrograde on the ecliptic; and the planets by
moving the plane of the ecliptic give them a direct mo-
tion, though much less than the former.   Consequently
the difference of the two is the mean precession, which
is proved both by theory and observation to be about
50″·1 annually (N. 143).

As the longitudes of all the fixed stars are increased
by this quantity, the effects of precession are soon de-
tected.   It was accordingly discovered by Hipparchus
in the year 128 before Christ, from a comparison of his
own observations with those of Timocharis 155 years
before.   In the time of Hipparchus, the entrance of the
sun into the constellation Aries was the beginning of
spring, but since that time the equinoctial points have
receded 30°, so that the constellations called the signs
of the zodiac are now at a considerable distance from
those divisions of the ecliptic which bear their names.
Moving at the rate of 50″·1 annually, the equinoctial
points will accomplish a revolution in 25,868 years.
But as the precession varies in different centuries the
extent of this period will be slightly modified.   Since
the motion of the sun is direct, and that of the equinoc-
tial points retrograde, he takes a shorter time to return
to the equator than to arrive at the same stars; so that
the tropical year of 365^d 5^h 48^m 49^s·7 must be increased
by the *time he takes* to move through an arc of 50″·1,

in order to have the length of the sidereal year. The time required is 20^m $19^s \cdot 6$, so that the sidereal year contains 365^d 6^h 9^m $9^s \cdot 6$ mean solar days.

The mean annual precession is subject to a secular variation; for although the change in the plane of the ecliptic in which the orbit of the sun lies be independent of the form of the earth, yet by bringing the sun, moon, and earth into different relative positions from age to age, it alters the direct action of the two first on the prominent matter at the equator: on this account the motion of the equinox is greater, by $0'' \cdot 455$ now than it was in the time of Hipparchus. Consequently the actual length of the tropical year is about $4^s \cdot 21$ shorter than it was at that time. The utmost change that it can experience from this cause amounts to 43 seconds.

Such is the secular motion of the equinoxes. But it is sometimes increased and sometimes diminished by periodic variations, whose periods depend upon the relative positions of the sun and moon with regard to the earth, and which are occasioned by the direct action of these bodies on the equator. Dr. Bradley discovered that by this action the moon causes the pole of the equator to describe a small ellipse in the heavens, the axes of which are $18'' \cdot 5$ and $13'' \cdot 674$, the longer being directed toward the pole of the ecliptic. The period of this inequality is about 19 years, the time employed by the nodes of the lunar orbit to accomplish a revolution. The sun causes a small variation in the description of this ellipse; it runs through its period in half a year. Since the whole earth obeys these motions they affect the position of its axis of rotation with regard to the starry heavens, though not with regard to the surface of the earth; for in consequence of precession alone the pole of the equator moves in a circle round the pole of the ecliptic in 25,868 years, and by nutation alone it describes a small ellipse in the heavens every 19 years, on each side of which it deviates every half year from the action of the sun. The real curve traced in the starry heavens by the imaginary prolongation of the earth's axis is compounded of these three motions (N. 144). This nutation in the earth's axis affects both the precession and obliquity with small periodic varia-

tions. But in consequence of the secular variation in the position of the terrestrial orbit, which is chiefly owing to the disturbing energy of Jupiter on the earth, the obliquity of the ecliptic is annually diminished, according to M. Bessel, by 0″·457. This variation in the course of ages may amount to 10 or 11 degrees; but the obliquity of the ecliptic to the equator can never vary more than 2° 42′ or 3°, since the equator will follow in some measure the motion of the ecliptic.

It is evident that the places of all the celestial bodies are affected by precession and nutation. Their longitudes estimated from the equinox are augmented by precession; but as it effects all the bodies equally, it makes no change in their relative positions. Both the celestial latitudes and longitudes are altered to a small degree by nutation; hence all observations must be corrected for these inequalities. In consequence of this real motion in the earth's axis the pole star, forming part of the constellation of the Little Bear, which was formerly 12° from the celestial pole, is now within 1° 24′ of it, and will continue to approach it till it is within ½°, after which it will retreat from the pole for ages; and 12,934 years hence the star *a* Lyræ will come within 5° of the celestial pole, and become the polar star of the northern hemisphere.

SECTION XII.

Mean and Apparent Sidereal Time—Mean and Apparent Solar Time— Equation of Time—English and French Subdivisions of Time—Leap Year—Christian Era—Equinoctial Time—Remarkable Eras depending upon the Position of the Solar Perigee—Inequality of the Lengths of the Seasons in the two Hemispheres—Application of Astronomy to Chronology—English and French Standards of Weights and Measures.

ASTRONOMY has been of immediate and essential use in affording invariable standards for measuring duration, distance, magnitude, and velocity. The mean sidereal day measured by the time elapsed between two consecutive transits of any star at the same meridian, and the mean sidereal year, which is the time included between two consecutive returns of the sun to the same star, are immutable units with which all great periods of

time are compared; the oscillations of the isochronous pendulum measure its smaller portions. By these invariable standards alone we can judge of the slow changes that other elements of the system may have undergone. Apparent sidereal time, which is measured by the transit of the equinoctial point at the meridian of any place, is a variable quantity, from the effects of precession and nutation. Clocks showing apparent sidereal time are employed for observation, and are so regulated that they indicate $0^h\ 0^m\ 0^s$ at the instant the equinoctial point passes the meridian of the observatory. And as time is a measure of angular motion, the clock gives the distances of the heavenly bodies from the equinox by observing the instant at which each passes the meridian, and converting the interval into arcs at the rate of 15° to an hour.

The returns of the sun to the meridian and to the same equinox or solstice, have been universally adopted as the measure of our civil days and years. The solar or astronomical day is the time that elapses between two consecutive noons or midnights. It is consequently longer than the sidereal day, on account of the proper motion of the sun during a revolution of the celestial sphere. But as the sun moves with greater rapidity at the winter than at the summer solstice, the astronomical day is more nearly equal to the sidereal day in summer than in winter. The obliquity of the ecliptic also affects its duration; for near the equinoxes the arc of the equator is less than the corresponding arc of the ecliptic, and in the solstices it is greater (N. 145). The astronomical day is therefore diminished in the first case, and increased in the second. If the sun moved uniformly in the equator at the rate of 59′ 8″·33 every day, the solar days would be all equal. The time therefore which is reckoned by the arrival of an imaginary sun at the meridian, or of one which is supposed to move uniformly in the equator, is denominated mean solar time, such as is given by clocks and watches in common life. When it is reckoned by the arrival of the real sun at the meridian it is apparent time, such as is given by dials. The difference between the time shown by a clock and a dial is the equation of time given in

the Nautical Almanac, sometimes amounting to as much
as sixteen minutes. The apparent and mean time coin-
cide four times in the year; when the sun's daily mo-
tion in right ascension is equal to 59′ 8″·33 in a mean
solar day, which happens about the 16th of April, the
16th of June, the 1st of September, and the 25th of
December.

The astronomical day begins at noon, but in common
reckoning the day begins at midnight. In England it is
divided into twenty-four hours, which are counted by
twelve and twelve; but in France astronomers, adopting
the decimal division, divide the day into ten hours, the
hour into one hundred minutes, and the minute into a
hundred seconds, because of the facility in computation,
and in conformity with their decimal system of weights
and measures. This subdivision is not now used in
common life, nor has it been adopted in any other
country; and although some scientific writers in France
still employ that division of time, the custom is begin-
ning to wear out. At one period during the French
revolution, the clock in the gardens of the Tuileries was
regulated to show decimal time. The mean length of
the day, though accurately determined, is not sufficient
for the purposes either of astronomy or civil life. The
tropical or civil year of 365^d 5^h 48^m 49^s·7, which is the
time elapsed between the consecutive returns of the sun
to the mean equinoxes or solstices, including all the
changes of the seasons, is a natural cycle peculiarly
suited for a measure of duration. It is estimated from
the winter solstice, the middle of the long annual night
under the north pole. But although the length of the
civil year is pointed out by nature as a measure of long
periods, the incommensurability that exists between the
length of the day and the revolution of the sun, renders
it difficult to adjust the estimation of both in whole num-
bers. If the revolution of the sun were accomplished
in 365 days, all the years would be of precisely the same
number of days, and would begin and end with the sun
at the same point of the ecliptic. But as the sun's revo-
lution includes the fraction of a day, a civil year and a
revolution of the sun have not the same duration. Since
the fraction is nearly the fourth of a day, in four years

it is nearly equal to a revolution of the sun, so that the addition of a supernumerary day every fourth year nearly compensates the difference. But in process of time further correction will be necessary, because the fraction is less than the fourth of a day. In fact, if a bissextile be suppressed at the end of three out of four centuries, the year so determined will only exceed the true year by an extremely small fraction of a day; and if in addition to this a bissextile be suppressed every 4000 years, the length of the year will be nearly equal to that given by observation. Were the fraction neglected, the beginning of the year would precede that of the tropical year, so that it would retrograde through the different seasons in a period of about 1507 years. The Egyptian year began with the heliacal rising of Sirius, and contained only 365 days, by which they lost one year in every 1461 years, their Sothaic period, or that cycle in which the heliacal rising of Sirius passes through the whole year and takes place again on the same day. The commencement of that cycle is placed by ancient chronologists in the year 1322 before the Christian era. The division of the year into months is very old and almost universal. But the period of seven days, by far the most permanent division of time, and the most ancient monument of astronomical knowledge, was used by the Brahmins in India with the same denominations employed by us, and was alike found in the calendars of the Jews, Egyptians, Arabs, and Assyrians. It has survived the fall of empires, and has existed among all successive generations, a proof of their common origin.

The day of the new moon immediately following the winter solstice in the 707th year of Rome, was made the 1st of January of the first year of Julius Cæsar. The 25th of December of his forty-fifth year is considered as the date of Christ's nativity; and the forty-sixth year of the Julian Calendar is assumed to be the first of our era. The preceding year is called the first year before Christ by chronologists, but by astronomers it is called the year 0. The astronomical year begins on the 31st of December at noon; and the date of an observation expresses the days and hours which have actually elapsed since that time.

Since solar and sidereal time are estimated from the passage of the sun and the equinoctial point across the meridian of each place, the hours are different at different places: while it is one o'clock at one place it is two at another, three at another, &c.; for it is obvious that it is noon at one part of the globe, at the same moment that it is midnight at another diametrically opposite to it; consequently an event which happens at one and the same instant of absolute time is recorded at different places, as having happened at different times. Therefore, when observations made at different places are to be compared, they must be reduced by computation to what they would have been had they been made under the same meridian. To obviate this, it was proposed by Sir John Herschel to employ mean equinoctial time, which is the same for all the world, and independent alike of local circumstances and inequalities in the sun's motion. It is the time elapsed from the instant the mean sun enters the mean vernal equinox, and is reckoned in mean solar days and parts of a day.

Some remarkable astronomical eras are determined by the position of the major axis of the solar ellipse, which depends upon the direct motion of the perigee (N. 102) and the precession of the equinoxes conjointly, the annual motion of the one being $11''\cdot8$, and that of the other $50''\cdot1$. Hence the axis, moving at the rate of $61''\cdot9$ annually, accomplishes a tropical revolution in $209\cdot84$ years. It coincided with the line of the equinoxes 4000 or 4089 years before the Christian era, much about the time chronologists assign for the creation of man. In 6483 the major axis will again coincide with the line of the equinoxes; but then the solar perigee will coincide with the equinox of autumn; whereas at the creation of man it coincided with the vernal equinox. In the year 1246 the major axis was perpendicular to the line of the equinoxes; then the solar perigee coincided with the solstice of summer, and the apogee with the solstice of winter. According to La Place, who computed these periods from different data, the last coincidence happened in the year 1250 of our era, which induced him to propose that year as a universal epoch, the vernal equinox of the year 1250 to be the first day of the first year.

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These eras can only be regarded as approximate, since ancient observations are too inaccurate, and modern observations too recent, to afford data for their precise determination.

The variation in the position of the solar ellipse occasions corresponding changes in the length of the seasons. In its present position spring is shorter than summer, and autumn longer than winter; and while the solar perigee continues as it now is between the solstice of winter and the equinox of spring, the period including spring and summer will be longer than that including autumn and winter. In this century the difference is between seven and eight days. The intervals will be equal toward the year 6483, when the perigee will coincide with the equinox of spring; but when it passes that point, the spring and summer taken together will be shorter than the period including the autumn and winter (N. 147). These changes will be accomplished in a tropical revolution of the major axis of the earth's orbit, which includes an interval of 20,984 years. Were the orbit circular, the seasons would be equal; their difference arises from the eccentricity of the orbit, small as it is; but the changes are so trifling as to be imperceptible in the short span of human life.

No circumstance in the whole science of astronomy excites a deeper interest than its application to chronology. "Whole nations," says La Place, "have been swept from the earth, with their languages, arts, and sciences, leaving but confused masses of ruins to mark the place where mighty cities stood; their history with the exception of a few doubtful traditions has perished; but the perfection of their astronomical observations marks their high antiquity, fixes the periods of their existence, and proves that even at that early time they must have made considerable progress in science." The ancient state of the heavens may now be computed with great accuracy; and by comparing the results of calculation with ancient observations, the exact period at which they were made may be verified if true, or if false their error may be detected. If the date be accurate and the observation good, it will verify the accuracy of modern tables, and will show to how many centuries

they may be extended without the fear of error. A few examples will show the importance of the subject.

At the solstices the sun is at his greatest distance from the equator, consequently his declination at these times is equal to the obliquity of the ecliptic (N. 148), which was formerly determined from the meridian length of the shadow of the stile of a dial on the day of a solstice. The lengths of the meridian shadow at the summer and winter solstices are recorded to have been observed at the city of Layang, in China, 1100 years before the Christian era. From these the distances of the sun from the zenith (N. 149) of the city of Layang are known. Half the sum of these zenith distances determines the latitude, and half their difference gives the obliquity of the ecliptic at the period of the observation; and as the law of the variation of the obliquity is known, both the time and place of the observations have been verified by computations from modern tables. Thus the Chinese had made some advances in the science of astronomy at that early period. Their whole chronology is founded on the observations of eclipses, which prove the existence of that empire for more than 4700 years. The epoch of the lunar tables of the Indians, supposed by Bailly to be 3000 years before the Christian era, was proved by La Place, from the acceleration of the moon, not to be more ancient than the time of Ptolemy, who lived in the second century after it. The great inequality of Jupiter and Saturn, whose cycle embraces 918 years, is peculiarly fitted for marking the civilization of a people. The Indians had determined the mean motions of these two planets in that part of their periods, when the apparent mean motion of Saturn was at the slowest, and that of Jupiter the most rapid. The periods in which that happened were 3102 years before the Christian era, and the year 1491 after it. The returns of comets to their perihelia may possibly mark the present state of astronomy to future ages.

The places of the fixed stars are affected by the precession of the equinoxes; and as the law of that variation is known, their positions at any time may be computed. Now Eudoxus, a contemporary of Plato, mentions a star situate in the pole of the equator, and it ap-

pears from computation that κ Draconis was not very
far from that place about 3000 years ago; but as it is
only about 2150 years since Eudoxus lived, he must
have described an anterior state of the heavens, sup-
posed to be the same that was mentioned by Chiron
about the time of the siege of Troy. Thus every cir-
cumstance concurs in showing that astronomy was cul-
tivated in the highest ages of antiquity.

It is possible that a knowledge of astronomy may lead
to the interpretation of hieroglyphical characters. As-
tronomical signs are often found on the ancient Egyptian
monuments, probably employed by the priests to record
dates. The author had occasion to witness an instance
of this most interesting application of astronomy, in as-
certaining the date of a papyrus, sent from Egypt by Mr.
Salt, in the hieroglyphical researches of the late Dr.
Thomas Young, whose profound and varied acquire-
ments do honor to his country, and to the age in which
he lived. The manuscript was found in a mummy case;
it proved to be a horoscope of the age of Ptolemy, and
its date was determined from the configuration of the
heavens at the time of its construction.

The form of the earth furnishes a standard of weights
and measures for the ordinary purposes of life, as well
as for the determination of the masses and distances of
the heavenly bodies. The length of the pendulum
vibrating seconds of mean solar time in the latitude of
London, forms the standard of the British measure of
extension. Its approximate length oscillating in vacuo
at the temperature of 62° of Fahrenheit, and reduced
to the level of the sea (N. 150), was determined by
Captain Kater to be 39·1393 inches. The weight of a
cubic inch of water at the temperature of 62° of
Fahrenheit, barometer 30 inches, was also determined
in parts of the imperial troy pound, whence a standard
both of weight and capacity was deduced. The French
have adopted the mètre equal to 3·2808992 English feet
for their unit of linear measure, which is the ten-mil-
lionth part of that quadrant of the meridian (N. 151),
passing through Formentera and Greenwich, the middle
of which is nearly in the forty-fifth degree of latitude.
Should the national standards of the two countries be

lost in the vicissitude of human affairs, both may be recovered; since they are derived from natural standards presumed to be invariable. The length of the pendulum would be found again with more facility than the mètre. But as no measure is mathematically exact, an error in the original standard may at length become sensible in measuring a great extent, whereas the error that must necessarily arise in measuring the quadrant of the meridian is rendered totally insensible by subdivision in taking its ten-millionth part. The French have adopted the decimal division, not only in time but also in their degrees, weights, and measures, on account of the very great facility it affords in computation. It has not been adopted by any other people, though nothing is more desirable than that all nations should concur in using the same standards, not only on account of convenience, but as affording a more definite idea of quantity. It is singular that the decimal division of the day, of degrees, weights, and measures, was employed in China 4000 years ago; and that at the time Ibn Junis made his observations at Cairo about the year 1000 of the Christian era, the Arabs were in the habit of employing the vibrations of the pendulum in their astronomical observations as a measure of time.

Section XIII.

Tides—Forces that produce them—Three kinds of Oscillations in the Ocean—The Semidiurnal Tides—Equinoctial Tides—Effects of the Declination of the Sun and Moon—Theory insufficient without Observation—Direction of the Tidal Wave—Height of Tides—Mass of Moon obtained from her Action on the Tides—Interference of Undulations—Impossibility of a Universal Inundation—Currents.

One of the most immediate and remarkable effects of a gravitating force external to the earth, is the alternate rise and fall of the surface of the sea twice in the course of a lunar day, or $24^h\ 50^m\ 28^s$ of mean solar time. As it depends upon the action of the sun and moon, it is classed among astronomical problems, of which it is by far the most difficult and its explanation the least satisfactory. The form of the surface of the ocean in equilibrio when revolving with the earth round its axis, is an ellipsoid

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flattened at the poles; but the action of the sun and moon, especially of the moon, disturbs the equilibrium of the ocean. If the moon attracted the center of gravity of the earth and all its particles with equal and parallel forces, the whole system of the earth and the waters that cover it would yield to these forces with a common motion, and the equilibrium of the seas would remain undisturbed. The difference of the forces and the inequality of their directions alone disturb the equilibrium.

It is proved by daily experience as well as by strict mathematical reasoning, that if a number of waves or oscillations be excited in a fluid by different forces, each pursues its course and has its effect independently of the rest. Now in the tides there are three kinds of oscillations depending on different causes, and producing their effects independently of each other, which may therefore be estimated separately.

The oscillations of the first kind, which are very small, are independent of the rotation of the earth; and as they depend upon the motion of the disturbing body in its orbit, they are of long periods. The second kind of oscillations depends upon the rotation of the earth, therefore their period is nearly a day. The oscillations of the third kind vary with an angle equal to twice the angular rotation of the earth, and consequently happen twice in twenty-four hours (N. 152). The first afford no particular interest, and are extremely small; but the difference of two consecutive tides depends upon the second. At the time of the solstices, this difference, which ought to be very great according to Newton's theory, is hardly sensible on our shores. La Place has shown that the discrepancy arises from the depth of the sea; and that if the depth were uniform, there would be no difference in the consecutive tides but that which is occasioned by local circumstances. It follows therefore that as this difference is extremely small, the sea considered in a large extent must be nearly of uniform depth; that is to say, there is a certain mean depth from which the deviation is not great. The mean depth of the Pacific Ocean is supposed to be about four or five miles, that of the Atlantic only three or four, which, however, is mere conjecture. From the formulæ which

determine the difference of the consecutive tides, it is proved that the precession of the equinoxes, and the nutation of the earth's axis, are the same as if the sea formed one solid mass with the earth.

Oscillations of the third kind are the semidiurnal tides so remarkable on our coasts. They are occasioned by the combined action of the sun and moon; but as the effect of each is independent of the other, they may be considered separately.

The particles of water under the moon are more attracted than the center of gravity of the earth, in the inverse ratio of the square of the distances. Hence they have a tendency to leave the earth, but are retained by their gravitation, which is diminished by this tendency. On the contrary, the moon attracts the center of the earth, more powerfully than she attracts the particles of water in the hemisphere opposite to her; so that the earth has a tendency to leave the waters, but is retained by gravitation, which is again diminished by this tendency. Thus the waters immediately under the moon are drawn from the earth, at the same time that the earth is drawn from those which are diametrically opposite to her, in both instances producing an elevation of the ocean of nearly the same height above the surface of equilibrium; for the diminution of the gravitation of the particles in each position is almost the same, on account of the distance of the moon being great in comparison of the radius of the earth. Were the earth entirely covered by the sea, the waters thus attracted by the moon would assume the form of an oblong spheroid whose greater axis would point toward the moon; since the columns of water under the moon, and in the direction diametrically opposite to her, are rendered lighter in consequence of the diminution of their gravitation; and in order to preserve the equilibrium, the axes 90° distant would be shortened. The elevation, on account of the smaller space to which it is confined, is twice as great as the depression; because the contents of the spheroid always remain the same. If the waters were capable of assuming the form of equilibrium instantaneously, that is the form of the spheroid, its summit would always point to the moon notwithstanding the earth's rotation. But on

account of their resistance, the rapid motion produced in them by rotation prevents them from assuming at every instant the form which the equilibrium of the forces acting upon them requires. Hence on account of the inertia of the waters, if the tides be considered relatively to the whole earth and open seas, there is a meridian about 30° eastward of the moon, where it is always high water both in the hemisphere where the moon is and in that which is opposite. On the west side of this circle the tide is flowing, on the east it is ebbing, and on every part of the meridian at 90° distant it is low water. This great wave, which follows all the motions of the moon as far as the rotation of the earth will permit, is modified by the action of the sun, the effects of whose attraction are in every respect like those produced by the moon, though greatly less in degree. Consequently a similar wave, but much smaller, raised by the sun tends to follow his motions, which at times combines with the lunar wave, and at others opposes it, according to the relative positions of the two luminaries; but as the lunar wave is only modified a little by the solar, the tides must necessarily happen twice in a day, since the rotation of the earth brings the same point twice under the meridian of the moon in that time, once under the superior and once under the inferior meridian.

In the semidiurnal tides there are two phenomena particularly to be distinguished, one occurring twice in a month, and the other twice in a year.

The first phenomenon is that the tides are much increased in the syzygies, or at the time of new and full moon (N. 153). In both cases the sun and moon are in the same meridian: for when the moon is new they are in conjunction; and when she is full they are in opposition. In each of these positions, their action is combined to produce the highest or spring tides under that meridian, and the lowest in those points that are 90° distant. It is observed that the higher the sea rises in full tide, the lower it is in the ebb. The neap tides take place when the moon is in quadrature; they neither rise so high nor sink so low as the spring tides. The spring tides are much increased when the moon is in perigee,

she is then nearest to the earth. It is evident
e strong tides must happen twice in a month,
that time the moon is once new and once full.
second phenomenon in the tides is the augmen-
ccurring at the time of the equinoxes when the
eclination (N. 154) is zero, which happens twice
ear. The greatest tides take place when a new
moon happens near the equinoxes, while the
in perigee. The inclination of the moon's orbit
cliptic is 5° 8′ 47″·9; hence in the equinoxes the
f the moon would be increased if her node were
ide with her perigee; for it is clear that the ac-
the sun and moon on the ocean is most direct
ense when they are in the plane of the equator,
the same meridian, and when the moon in con-
n or opposition is at her least distance from the
The spring tides which happen under all these
le circumstances must be the greatest possible.
uinoctial gales often raise them to a great height.
these remarkable variations, there are others
from the declination or angular distance of the
l moon from the plane of the equator, which have
influence on the ebb and flow of the waters. The
l moon are continually making the circuit of the
s at different distances from the plane of the
·, on account of the obliquity of the ecliptic and
ination of the lunar orbit. The moon takes about
-nine days and a half to vary through all her de-
ns, which sometimes extend $28\frac{3}{4}$ degrees on each
the equator, while the sun requires nearly $365\frac{1}{4}$
accomplish his motion from tropic to tropic
about $23\frac{1}{2}$ degrees; so that their combined mo-
uses great irregularities, and at times their at-
forces counteract each other's effects to a certain
; but on an average the mean monthly range of
on's declination is nearly the same as the annual
f the declination of the sun: consequently the
tides take place within the tropics, and the low-
vard the poles. The declination of the moon
e causes the two tides of the same day to rise to
l heigbts; this diurnal inequality of course van-
hen the moon is in the equator.

Both the height and time of high water are thus perpetually changing; therefore, in solving the problem, it is required to determine the heights to which the tides rise, the times at which they happen, and the daily variations. Theory and observation show that each partial tide increases as the cube of the apparent diameter, or of the parallax of the body which produces it, and that it diminishes as the square of the cosine of the declination of that body (N. 154); for the greater the apparent diameter, the nearer the body, and the more intense its action on the sea; but the greater the declination, the less the action, because it is less direct.

The periodic motions of the waters of the ocean, on the hypothesis of an ellipsoid of revolution entirely covered by the sea, are very far from according with observation. This arises from the very great irregularities in the surface of the earth, which is but partially covered by the sea; from the variety in the depths of the ocean, the manner in which it is spread out on the earth, the position and inclination of the shores, the currents, and the resistance the waters meet with—causes impossible to estimate, but which modify the oscillations of the great mass of the ocean. However, amid all these irregularities, the ebb and flow of the sea maintain a ratio to the forces producing them sufficient to indicate their nature and to verify the law of the attraction of the sun and moon on the sea. La Place observes that the investigation of such relations between cause and effect is no less useful in natural philosophy than the direct solution of problems either to prove the existence of the causes or to trace the laws of their effects. Like the theory of probabilities, it is a happy supplement to the ignorance and weakness of the human mind. Thus the problem of the tides does not admit of a general solution. It is, indeed, necessary to analyze the general phenomena which ought to result from the attraction of the sun and moon; but these must be corrected in each particular case by local observations modified by the extent and depth of the sea, and the peculiar circumstances of the place.

Since the disturbing action of the sun and moon can only become sensible in a very great extent of water,

the Pacific Ocean must be one of the principal sources of our tides; but, in consequence of the rotation of the earth and the inertia of the ocean, high water does not happen till some time after the moon's southing (N. 155). The tide raised in that world of waters is transmitted to the Atlantic, from which sea it moves in a northerly direction along the coasts of Africa and Europe, arriving later and later at each place. This great wave, however, is modified by the tide raised in the Atlantic, which sometimes combines with that from the Pacific in raising the sea, and sometimes is in opposition to it, so that the tides only rise in proportion to their difference. This vast combined wave, reflected by the shores of the Atlantic, extending nearly from pole to pole, still coming northward, pours through the Irish and British Channels into the North Sea; so that the tides in our ports are modified by those of another hemisphere. Thus the theory of the tides in each port, both as to their height and the times at which they take place, is really a matter of experiment, and can only be perfectly determined by the mean of a very great number of observations, including several revolutions of the moon's nodes.

The height to which the tides rise is much greater in narrow channels than in the open sea, on account of the obstructions they meet with. The sea is so pent up in the British Channel that the tides sometimes rise as much as fifty feet at St. Malo on the coast of France; whereas on the shores of some of the South Sea islands near the center of the Pacific they do not exceed one or two feet. The winds have great influence on the height of the tides, according as they conspire with or oppose them; but the actual effect of the wind in exciting the waves of the ocean extends very little below the surface. Even in the most violent storms, the water is probably calm at the depth of ninety or a hundred feet. The tidal wave of the ocean does not reach the Mediterranean nor the Baltic, partly from their position and partly from the narrowness of the Straits of Gibraltar and of the Categat, but it is very perceptible in the Red Sea and in Hudson's Bay. In high latitudes, where the ocean is less directly under the influence of the luminaries, the rise and fall of the sea is inconsider-

able, so that in all probability there is no tide at the poles, or only a small annual and monthly tide. The ebb and flow of the sea are perceptible in rivers to a very great distance from their estuaries. In the Straits of Pauxis, in the river of the Amazons, more than five hundred miles from the sea, the tides are evident. It requires so many days for the tide to ascend this mighty stream, that the returning tides meet a succession of those which are coming up; so that every possible variety occurs at some part or other of its shores, both as to magnitude and time. It requires a very wide expanse of water to accumulate the impulse of the sun and moon, so as to render their influence sensible; on that account the tides in the Mediterranean and Black Sea are scarcely perceptible.

These perpetual commotions in the waters are occasioned by forces that bear a very small proportion to terrestrial gravitation: the sun's action in raising the ocean is only the $\frac{1}{38448000}$ of gravitation at the earth's surface, and the action of the moon is little more than twice as much; these forces being in the ratio of 1 to 2·35333, when the sun and moon are at their mean distances from the earth. From this ratio the mass of the moon is found to be only the $\frac{1}{75}$ part of that of the earth. Had the action of the sun on the ocean been exactly equal to that of the moon, there would have been no neap tides, and the spring tides would have been of twice the height which the action of either the sun or moon would have produced separately; a phenomenon depending upon the interference of the waves or undulations.

A stone plunged into a pool of still water occasions a series of waves to advance along the surface, though the water itself is not carried forward, but only rises into heights and sinks into hollows, each portion of the surface being elevated and depressed in its turn. Another stone of the same size thrown into the water near the first, will occasion a similar set of undulations. Then if an equal and similar wave from each stone arrive at the same spot at the same time, so that the elevation of the one exactly coincides with the elevation of the other, their united effect will produce a wave twice the size of

either.   But if one wave precede the other by exactly
half an undulation, the elevation of the one will coincide
with the hollow of the other, and the hollow of the one
with the elevation of the other; and the waves will so
entirely obliterate one another, that the surface of the
water will remain smooth and level.   Hence if the length
of each wave be represented by 1, they will destroy one
another at intervals of $\frac{1}{2}$, $\frac{3}{2}$, $\frac{5}{2}$, &c., and will combine
their effects at the intervals 1, 2, 3, &c.   It will be found
according to this principle, when still water is disturbed
by the fall of two equal stones, that there are certain
lines on its surface of a hyperbolic form, where the
water is smooth in consequence of the waves oblitera-
ting each other; and that the elevation of the water in
the adjacent parts corresponds to both the waves united
(N. 156).   Now in the spring and neap tides arising
from the combination of the simple soli-lunar waves, the
spring tide is the joint result of the combination when
they coincide in time and place; and the neap tide hap-
pens when they succeed each other by half an interval,
so as to leave only the effect of their difference sensible.
It is therefore evident that if the solar and lunar tides
were of the same height, there would be no difference,
consequently no neap tides, and the spring tides would
be twice as high as either separately.   In the port of
Batsha in Tonquin, where the tides arrive by two chan-
nels of lengths corresponding to half an interval, there
is neither high nor low water, on account of the inter-
ference of the waves.

The initial state of the ocean has no influence on the
tides; for whatever its primitive conditions may have
been, they must soon have vanished by the friction and
mobility of the fluid.   One of the most remarkable cir-
cumstances in the theory of the tides is the assurance,
that in consequence of the density of the sea being only
one-fifth of the mean density of the earth, and the earth
itself increasing in density toward the center, the sta-
bility of the equilibrium of the ocean never can be sub-
verted by any physical cause.   A general inundation
arising from the mere instability of the ocean is there-
fore impossible.   A variety of circumstances however
tend to produce partial variations in the equilibrium of

and takes a different form. Heat appears to have a great influence on the phenomena of crystalization, not only when the particles of matter are free, but even when firmly united, for it dissolves their union and gives them another determination. Professor Mitscherlich found that prismatic crystals of sulphate of nickel (N. 161) exposed to a summer's sun in a close vessel, had their internal structure so completely altered without any exterior change, that when broken open they were composed internally of octahedrons with square bases. The original aggregation of the internal particles had been dissolved, and a disposition given to arrange themselves in a crystaline form. Crystals of sulphate of magnesia and of sulphate of zinc, gradually heated in alcohol till it boils, lose their transparency by degrees, and when opened are found to consist of innumerable minute crystals totally different in form from the whole crystals; and prismatic crystals of zinc (N. 162) are changed in a few seconds into octahedrons by the heat of the sun: other instances might be given of the influence of even moderate degrees of temperature on molecular attraction in the interior of substances. It must be observed that these experiments give entirely new views with regard to the constitution of solid bodies. We are led from the mobility of fluids to expect great changes in the relative positions of their molecules, which must be in perpetual motion even in the stillest water or calmest air; but we were not prepared to find motion to such an extent in the interior of solids. That their particles are brought nearer by cold and pressure, or removed farther from one another by heat, might be expected; but it could not have been anticipated that their relative positions could be so entirely changed as to alter their mode of aggregation. It follows from the low temperature at which these changes are effected, that there is probably no portion of inorganic matter that is not in a state of relative motion.

Professor Mitscherlich's discoveries with regard to the forms of crystalized substances, as connected with their chemical charcter, have thrown additional light on the constitution of material bodies. There is a certain set of crystaline forms which are not susceptible of

are perpetually describing between the parallels of eleven and forty-three degrees of latitude, may be accomplished by any one particle in two years and ten months. In the center of this current is situated the wide field of floating sea-weed called the grassy sea. Besides this there are branches of the Gulf-stream, which convey the fruits, seeds, and a portion of the warmth of the tropical climates to our northern shores.

The general westward motion of the South Sea, together-er with the south polar current, produce various water-courses in the Pacific and Indian Oceans, according as the one or the other prevails. The western set of the Pacific causes currents to pass on each side of Australia, while the polar stream rushes along the bay of Bengal: the westerly current again becomes most powerful to-ward Ceylon and the Maldives, whence it stretches by the extremity of the Indian peninsula past Madagascar, to the most southern point of the continent of Africa, where it mingles with the general motion of the seas. Icebergs are sometimes drifted as far as the Azores from the north pole, and from the south pole they have come even to the Cape of Good Hope. But the ice which encircles the south pole extends to lower latitudes by 10° than that which surrounds the north. In conse-quence of the polar current Sir Edward Parry was obliged to give up his attempt to reach the north pole in the year 1827, because the fields of ice were drifting to the south faster than his party could travel over them to the north.

As distinct currents of air traverse the atmosphere in horizontal strata, so in all probability under currents in the ocean flow in opposite directions from those on the surface ; and there is every reason to believe that the cold waters, deep below the surface of the sea in the equinoctial regions, are brought by submarine currents from the poles, though it is not easy to prove their ex-istence.

SECTION XIV.

Repulsive Force — Interstices or Pores—Elasticity—Mossotti's Theory—
Gravitation brought under the same law with Molecular Attraction and
Repulsion—Gases reduced to Liquids by Pressure—Intensity of the Co-
hesive Force—Effects of Gravitation—Effects of Cohesion—Minuteness
of the ultimate Atoms of Matter—Limited Height of the Atmosphere—
Theory of Definite Proportions and Relative Weight of Atoms—Dr. Far-
aday's Discoveries with regard to Affinity—Composition of Water by a
Plate of Platina—Crystallization—Cleavage—Isomorphism—Matter con-
sists of Atoms of Definite Form—Capillary Attraction.

THE oscillations of the atmosphere and its action
upon rays of light coming from the heavenly bodies,
connect the science of astronomy with the equilibrium
and movements of fluids, and the laws of molecular
attraction. Hitherto that force has been under consid-
eration which acts upon masses of matter at sensible
distances; but now the effects of such forces are to be
considered as act at inappreciable distances upon the
ultimate atoms of material bodies.

All substances consist of an assemblage of material
particles, which are far too small to be visible by any
means human ingenuity has yet been able to devise,
and which are much beyond the limits of our percep-
tions. Since every known substance may be reduced
in bulk by pressure, it follows that the particles of mat-
ter are not in actual contact, but are separated by inter-
stices, owing to the repulsive principle that maintains
them at extremely minute distances from one another.
It is evident that the smaller the interstitial spaces
the greater the density. These spaces appear in
some cases to be filled with air, as may be infer-
red from certain semi-opaque minerals and other sub-
stances becoming transparent when plunged into water;
sometimes they may possibly contain some unknown
and highly elastic fluid, such as Sir David Brewster has
discovered in the minute cavities of various minerals,
which occasionally causes these substances to explode
with violence when under the hands of the lapidary,
but in general they seem to our senses to be void; yet
as it is inconceivable that the particles of matter should
act upon one another without some means of commu-

nication, there is every reason to presume that the interstices of material substances contain a portion of that subtle ethereal and elastic fluid with which the regions of space are replete.

Substances compressed by a sufficient force, are said to be more or less elastic according to the facility with which they regain their bulk or volume when the pressure is removed; a property which depends upon the repulsive force of their particles, and the effort required to compress the substance is a measure of the intensity of that repulsive force which varies with the nature of the substance.

By the laws of gravitation the particles of matter attract one another when separated by sensible distances; and as they repel each other when they are inappreciably near, it recently occurred to Professor Mossotti of Pisa, that there might be some intermediate distance at which the particles might neither attract nor repel one another, but remain balanced in that stable equilibrium which they are found to maintain in every material substance solid and fluid.

It has long been a hypothesis among philosophers that electricity is the agent which binds the particles of matter together. We are totally ignorant of the nature of electricity, but it is generally supposed to be an ethereal fluid in the highest state of elasticity surrounding every particle of matter; and as the earth and the atmosphere are replete with it in a latent state, there is every reason to believe that it is unbounded, filling the regions of space.

The celebrated Franklin was the first who explained the phenomena of electricity in repose, by supposing the molecules of bodies to be surrounded by an atmosphere of the electric fluid; and that while the electric atoms repel one another, they are attracted by the material molecules of the body. These forces of attraction and repulsion were afterward proved by Coulomb to vary inversely as the squares of the distance. The hypothesis of Franklin was reduced to a mathematical theory by Æpinus, and the most refined analysis has been employed by the Baron Poisson in explanation of electric phenomena. Still these philosophers were un-

7   I

able to reconcile the attraction of the molecules of matter inversely as the squares of the distance as proved by Newton, with their mutual repulsion according to the same law. But Professor Mossotti has recently shown, by a very able analysis, that there are strong grounds for believing that not only the molecular forces which unite the particles of material bodies depend on the electric fluid, but that even gravitation itself, which binds world to world and sun to sun, can no longer be regarded as an ultimate principle, but the residual portion of a far more powerful force generated by that energetic agent which pervades creation.

It is true that this connection between the molecular forces and gravitation depends upon a hypothesis; but in the greater number of physical investigations, some hypothesis is requisite in the first instance to aid the imperfection of our senses. Yet, when the phenomena of nature accord with the assumption, we are justified in believing it to be a general law.

As the particles of material bodies are not in actual contact, Professor Mossotti supposes that each is encompassed by an atmosphere of the ethereal fluid; that the atoms of the fluid repel one another; that the molecules of matter repel one another, but with less intensity; and that there is a mutual attraction between the particles of matter and the atoms of the fluid. Forces which we know to exist, and which he assumes to vary inversely as squares of the distance. The following important results have been obtained by the professor from the adjustment of these three forces:—

When the material molecules of a body are inappreciably near to one another, they mutually repel each other with a force which diminishes rapidly as the infinitely small distance between the material molecules augments, and at last vanishes. When the molecules are still farther apart, the force becomes attractive. At that particular point where the change takes place, the forces of repulsion and attraction balance each other, so that the molecules of a body are neither disposed to approach nor recede, but remain in equilibrio. If we try to press them nearer, the repulsive force resists the attempt; and if we endeavor to break the body so as to

tear the particles asunder, the attractive force predom-
inates and keeps them together. This is what consti-
tutes the cohesive force, or force of aggregation, by
which the molecules of all substances are united. The
limits of the distance at which the negative action be-
comes positive vary according to the temperature and
nature of the molecules, and determine whether the
body which they form be solid, liquid, or aëriform.

Beyond this neutral point, the attractive force in
creases as the distance between the molecules augments,
till it attains a maximum; when the particles are more
apart it diminishes; and as soon as they are separated
by finite or sensible distances, it varies directly as their
mass and inversely as the squares of the distance,
which is precisely the law of universal gravitation.

Thus on the hypothesis that the mutual repulsion
between the electric atoms is a little more powerful
than the mutual repulsion between the particles of mat-
ter, the ether and the matter attract each other with
unequal intensities, which leave an excess of attractive
force constituting gravitation. As the gravitating force
is in operation wherever there is matter, the ethereal
electric fluid must encompass all the bodies in the uni-
verse; and as it is utterly incomprehensible that the
celestial bodies should exert a reciprocal attraction
through a void, this important investigation of Professor
Mossotti furnishes additional presumption in favor of a
universal ether, already all but proved by the motion of
comets and the theory of light.

In aëriform fluids the particles of matter are more
remote from each other than in liquids and solids; but
the pressure may be so great as to reduce an aëriform
fluid to a liquid, and a liquid to a solid. Dr. Faraday
has reduced some of the gases to a liquid state by very
great compression; but although atmospheric air is
capable of a diminution of volume to which we do not
know the limit, it has hitherto always retained its
gaseous properties, and resumes its primitive volume
the instant the pressure is removed.

If the particles approach sufficiently near to produce
equilibrium between the attractive and repulsive forces,
but not near *enough to* admit of any influence from

ticity of the air.   The definite proportions of chemical
compounds afford one of the best proofs that divisibility
of matter has a limit.   The cohesive force which has
been the subject of the preceding considerations, only
unites particles of the same kind of matter; whereas
affinity, which is the cause of chemical compounds, is
the mutual attraction between particles of different
kinds of matter, and is merely a result of the electrical
state of the particles, chemical affinity and electricity
being only forms of the same powers.

It is a permanent and universal law in all unorganized
bodies hitherto analyzed, that the composition of sub-
stances is definite and invariable, the same compound
always consisting of the same elements united together
in the same proportions.   Two substances may indeed
be mixed; but they will not combine to form a third
substance different from both, unless their component
particles unite in definite proportions, that is to say, one
part by weight of one of the substances will unite with
one part by weight of the other, or with two parts, or
three, or four, &c., so as to form a new substance; but
in any other proportions they will only be mechanically
mixed.   For example, one part by weight of hydrogen
gas will combine with eight parts by weight of oxygen
gas and form water; or it will unite with sixteen parts
by weight of oxygen, and form a substance called
deutoxide of hydrogen; but added to any other weight
of oxygen, it will produce one or both of these com-
pounds mingled with the portion of oxygen or hydrogen
in excess.   The law of definite proportion established
by Dr. Dalton, on the principle that every compound
body consists of a combination of the atoms of its con-
stituent parts, is of universal application, and is in fact
one of the most important discoveries in physical science,
furnishing information previously unhoped for with re-
gard to the most secret and minute operations of nature,
in disclosing the relative weights of the ultimate atoms
of matter.   Thus an atom of oxygen uniting with an
atom of hydrogen forms the compound water; but as
every drop of water, however small, consists of eight
parts by weight of oxygen and one part by weight of
hydrogen, it follows that an atom of oxygen is eight

times heavier than an atom of hydrogen. In the same manner sulphuretted hydrogen gas consists of sixteen parts by weight of sulphur and one of hydrogen: therefore, an atom of sulphur is sixteen times heavier than an atom of hydrogen. Also carbonic oxide is constituted of six parts by weight of carbon, and eight of oxygen; and as an atom of oxygen has eight times the weight of an atom of hydrogen, it follows that an atom of carbon is six times heavier than one of hydrogen. Since the same definite proportion holds in the composition of all substances that have been examined, it may be concluded that there are great differences in the weights of the ultimate particles of matter. M. Gay Lussac discovered that gases unite together by their bulk or volumes, in such simple and definite proportions as one to one, one to two, one to three, &c. For example, one volume or measure of oxygen unites with two volumes or measures of hydrogen in the formation of water.

Affinity modified by the electrical condition of the particles of matter, has hitherto been believed to be the cause of chemical combinations. However, Dr. Faraday has proved by experiments on bodies both in solution and fusion, that chemical affinity is merely a result of the electrical state of the particles of matter. Now it must be observed that the composition of bodies as well as their decomposition, may be accomplished by means of electricity; and Dr. Faraday has found that this chemical composition and decomposition, by a given current of electricity, is always accomplished according to the laws of definite proportions; and that the quantity of electricity requisite for the decomposition of a substance is exactly the quantity necessary for its composition. Thus the quantity of electricity which can decompose a grain weight of water is exactly equal to the quantity of electricity which unites the elements of that grain of water together, and is equivalent to the quantity of atmospheric electricity which is active in a very powerful thunder-storm. These laws are universal, and are of that high and general order that characterize all great discoveries, and perfectly agree with Professor Mossotti's theory.

known by experience to be of extreme tenuity at very small heights. The barometer rises in proportion to the super-incumbent pressure. At the level of the sea in the latitude of 45° and at the temperature of melting ice, the mean height of the barometer being 29·922 inches, the density of the air is to the density of a similar volume of mercury as 1 to 10477·9. Consequently the height of the atmosphere supposed to be of uniform density would be about 4·95 miles. But as the density decreases upward in geometrical progression it is considerably higher, probably about fifty miles; at that height it must be of extreme tenuity, for the decrease in density is so rapid that three fourths of all the air contained in the atmosphere is within four miles of the earth; and, as its superficial extent is 200 millions of square miles, its relative thickness is less than that of a sheet of paper when compared with its breadth. The air even on mountain tops is sufficiently rare to diminish the intensity of sound, to affect respiration, and to occasion a loss of muscular strength. The blood burst from the lips and ears of M. de Humboldt as he ascended the Andes; and he experienced the same difficulty in kindling and maintaining a fire at great heights which Marco Polo the Venetian felt on the mountains of Central Asia. M. Gay-Lussac and M. Biot ascended in a balloon to the height of 4·36 miles, which is the greatest elevation that man has attained, and they suffered greatly from the rarity of the air. It is true that at the height of thirty-seven miles, the atmosphere is still dense enough to reflect the rays of the sun when 18° below the horizon; but the tails of comets show that extremely attenuated matter is capable of reflecting light. And although, at the height of fifty miles, the bursting of the meteor of 1783 was heard on earth like the report of a cannon, it only proves the immensity of the explosion of a mass half a mile in diameter, which could produce a sound capable of penetrating air three thousand times more rare than that we breathe. But even these heights are extremely small when compared with the radius of the earth.

The mean pressure of the atmosphere is not the same all over the globe. It is less at the equator than at the

or in the higher latitudes, in consequence of the
if the heated air from the surface of the earth ;
i also on the shores of the Baltic sea than it is
ce, probably from some permanent eddy in the
ing from the conformation of the surrounding
id to similar local causes those barometric depres-
ay be attributed which have been observed by
ian, near the Sea of Ochotzk in Eastern Siberia,
Captain Foster near Cape Horn.

e are various periodic oscillations in the atmos-
which, rising and falling like waves in the sea,
a corresponding changes in the height of the
ter, but they differ as much from the trade winds,
ns, and other currents, as the tides of the sea do
ie Gulf-stream and other oceanic rivers.   The
l moon disturb the equilibrium of the atmosphere
r attraction, and produce annual undulations which
ieir maximum altitudes at the equinoxes and their
l at the solstices.   There are also lunar tides
ebb and flow twice in the course of a lunation.
urnal tides, which accomplish their rise and fall
hours, are greatly modified by the heat of the
Between the tropics the barometer attains its
um height about nine in the morning, then sinks
ee or four in the afternoon; it again rises and
a second maximum about nine in the evening,
en it begins to fall and reaches a second minimum
e in the morning, again to pursue the same course.
ling to M. Bouvard, the amount of the oscillations
equator is proportional to the temperature, and
r parallels it varies as the temperature and the
of the cosine of the latitude conjointly, conse-
y it decreases from the equator to the poles, but
mewhat greater in the day than in the night.
ides these small undulations, there are vast waves
ually moving over the continents and oceans in
te and independent systems, being confined to
et very extensive districts, probably occasioned by
ontinued rains or dry weather over large tracts of
y.   By numerous barometrical observations made
aneously in both hemispheres, the courses of sev-
ive been traced, some of which occupy twenty-four

and others thirty-six hours to accomplish their rise and
fall. One especially of these vast barometric waves, many
hundreds of miles in breadth, has been traced over the
greater part of Europe, and not its breadth only, but also
the direction of its front and its velocity have been clearly
ascertained. Although like all other waves these are
but moving forms, yet winds arise dependent on them
like tide streams in the ocean. Mr. Birt has deter-
mined the periods of other waves of still greater extent
and duration, two of which require seventeen days to
rise and fall, and another took thirteen days to complete
its undulation. Since each oscillation has its perfect
effect independently of the others, each one is marked
by a change in the barometer, and this is beautifully
illustrated by curves constructed from a series of obser-
vations. The general form of the curve shows the
course of the principal wave, while small undulations in
its outline mark the maxima and minima of the minor
oscillations.

The trade-winds, which are the principal currents in
the atmosphere, are only a particular case of those very
general laws which regulate the motion of the winds
depending on the rarefaction of the air combined with
the rotation of the earth on its axis.

The heat of the sun occasions these aërial currents
by rarefying the air at the equator, which causes the
cooler and more dense part of the atmosphere to rush
along the surface of the earth from the poles toward the
equator, while that which is heated is carried along the
higher strata to the poles, forming two counter-currents
in the direction of the meridian. But the rotatory ve-
locity of the air corresponding to its geographical posi-
tion decreases toward the poles. In approaching the
equator it must therefore revolve more slowly than the
corresponding parts of the earth, and the bodies on the
surface of the earth must strike against it with the ex-
cess of their velocity, and by its reaction they will meet
with a resistance contrary to their motion of rotation.
So that the wind will appear to a person supposing him-
self to be at rest, to blow in a direction nearly though
not altogether contrary to the earth's rotation; because
these currents will still retain a part of their northerly

and southerly impetus, which, combining with their de-
ficiency of rotatory velocity, will make them appear to
blow from the north-east on one side of the equator and
from the south-east on the other, which is the general
direction of the trade-winds. But they are modified
both in intensity and direction by the seasons, by the
neighborhood of continents, and by the nature of the
soil, so that the phenomena are not the same in both
hemispheres. These winds, however, are not felt at all
under the line, because the easterly tendency of the
two great polar currents is gradually diminished as they
approach the equator by the friction of the earth, which
slowly imparts a portion of its rotatory velocity to them
as they pass along, and when they meet in the equator
they destroy one another's impetus. The equator does
not exactly coincide with the line which separates the
trade-winds north and south of it. That line of separa-
tion depends upon the total difference of heat in the two
hemispheres, arising from the distribution of land and
water, and other causes.

The polar currents from defect of rotatory velocity
tend, by their friction near the equator, to diminish the
velocity of the earth's rotation; while, on the contrary,
the equatorial or upper currents carry their excess of
rotatory velocity north and south. And as they occa-
sionally come to the surface in their passage to the poles,
they act on the earth by their friction as a strong south-
west wind in the northern hemisphere, and as a north-
west wind in the southern. In this manner the equili-
brium of rotation is maintained. Sir John Herschel
ascribes to this cause the western and south-western
gales so prevalent in our latitudes, and also the west
winds which are so constant in the North Atlantic.

There are many proofs of the existence of the coun-
ter-currents above the trade-winds. On the Peak of
Teneriffe the prevailing winds are from the west. The
ashes of the volcano of St. Vincent's, in the year 1812,
were carried to windward as far as Barbadoes by the
upper current. The captain of a Bristol ship declared
that on that occasion dust from St. Vincent's fell to the
depth of five inches on the deck at the distance of 500
miles to the eastward. Light clouds have frequently

been seen moving rapidly from west to east, at a very great height above the trade-winds, which were sweeping along the surface of the ocean in a contrary direction. Rains, clouds, and nearly all the other atmospheric phenomena occur below the height of 18,000 feet, and generally much nearer to the surface of the earth. They are owing to currents of air running upon each other in horizontal strata, and differing in their electric state, in temperature and moisture, as well as in velocity and direction.

The monsoons are steady currents six months in duration, owing to diminished atmospheric pressure at each tropic alternately from the heat of the sun, thereby producing a regular alternation of north and south winds, which combining their motion with that of the earth on its axis become a north-east wind in the northern hemisphere and a south-west in the southern; the former blows from April to October and the latter from October to April. The change from one to the other is attended by violent rains, with storms of thunder and lightning. From some peculiar conformation of the land and water, these winds are confined to the Arabian Gulf, the Indian Ocean, and the China Sea.

When north and south winds blow alternately, the wind at any place will veer in one uniform direction through every point of the compass, provided the one begins before the other has ceased. In the northern hemisphere a north wind sets out with a smaller degree of rotatory motion than the places have at which it successively arrives, consequently it passes through all the points of the compass from N. to N. E. and E. A current from the south, on the contrary, sets out with a greater rotatory velocity than the places have at which it successively arrives, so by the rotation of the earth it is deflected from S. to S. W. and W. Now if the vane at any place should have veered from the N. through N. E. to E., and a south wind should spring up, it would combine its motion with the former and cause the vane to turn successively from the E. to S. E. and S. But by the earth's rotation this south wind will veer to the S. W. and W., and if a north wind should now arise, it would combine its motion with that of the west and

cause it to veer to the N. W. and N.   Thus two alternations of north and south wind will cause the vane at any place to go completely round the compass, from N. to E., S., W., and N. again.   At the Royal Observatory at Greenwich, the wind accomplishes five circuits in that direction in the course of a year.   When circumstances combine to produce alternate north and south winds in the southern hemisphere, the gyration is in the contrary direction.   Although the general tendency of the wind may be rotatory, and is so in many instances, at least for part of the year, yet it is so often counteracted by local circumstances, that the winds are in general very irregular ; every disturbance in atmospheric equilibrium from heat or any other cause producing a corresponding wind.   The most prevalent winds in Europe are the N. E. and S. W.; the former arises from the north polar current, and the latter from causes already mentioned.   The law of the wind's rotation was noticed by Dr. Dalton, but has been developed by Professor Dove, of Berlin.

Hurricanes are those storms of wind in which the portion of the atmosphere that forms them revolves in a horizontal circuit round a vertical or somewhat inclined axis of rotation, while the axis itself, and consequently the whole storm, is carried forward along the surface of the globe, so that the direction in which the storm is advancing is quite different from the direction in which the rotatory current may be blowing at any point.   In the West Indies, where hurricanes are frequent and destructive, they generally originate in the tropical regions near the inner boundary of the trade-winds, and are probably owing to a portion of the superior current of wind penetrating through the lower.   By far the greater number of Atlantic hurricanes have begun eastward of the lesser Antilles or Caribbean Islands.

In every case the axis of the storm moves in an elliptical or parabolic curve, having its vertex in or near the tropic of Cancer, which marks the external limit of the trade-winds north of the equator.   As the motion before it reaches the tropic is in a straight line from S. E. to N. W., and after it has passed it from S. W. to N. E., the bend of the curve is turned toward Florida

and the Carolinas. In the southern hemisphere the body of the storms moves in exactly the opposite direction. The hurricanes which originate south of the equator, and whose initial path is from N. E. to S. W., bend round at the tropic of Capricorn, and then bend from N. W. to S. E.

The extent and velocity of these storms are great; for instance, the hurricane that took place on the 12th of August, 1830, was traced from the eastward of the Caribbee Islands to the bank of Newfoundland, a distance of more than 3000 miles, which it passed over in six days. Although the hurricane of the 1st of September, 1821, was not so extensive, its velocity was greater, as it moved at the rate of 30 miles an hour: small storms are generally more rapid than those of greater dimensions.

The action of these storms seems to be at first confined to the stratum of air nearest the earth, and then they seldom appear to be more than a mile high, though sometimes they are raised higher; or even divided by a mountain into two separate storms, each of which continues its new path and gyrations with increased violence. This occurred in the gale of the 25th of December, 1821, in the Mediterranean, when the Spanish mountains and the Maritime Alps became new centers of motion.

By the friction of the earth the axis of the storm bends a little forward, so that the whirling motion begins in the higher regions of the atmosphere before it is felt on the earth. This causes a continual intermixture of the lower and warmer strata of air with those that are higher and colder, producing torrents of rain and violent electric explosions.

The rotation is different in direction in different hemispheres, though always alike in the same. In the northern hemisphere the gyration is contrary to the movement of the hands of a watch, that is to say, the wind revolves from east round through the north to the west, south and east again; while in the southern hemisphere, the rotation about the axis of the storm is in the contrary direction.

The breadth of the whirlwind is greatly augmented

when the path of the storm changes on crossing the tropic. The vortex of a storm has covered an extent of the surface of the globe 500 miles in diameter.

The revolving motion accounts for the sudden and violent changes observed during hurricanes. In consequence of the rotation of the air, the wind blows in opposite directions on each side of the axis of the storm, and the violence of the blast increases from the circumference toward the center of gyration, but in the center itself the air is in repose : hence, when the body of the storm passes over a place, the wind begins to blow moderately, and increases to a hurricane as the center of the whirlwind approaches ; then, in a moment, a dead and awful calm succeeds, suddenly followed by a renewal of the storm in all its violence, but now blowing in a direction diametrically opposite to its former course. This happened at the Island of St. Thomas, on the 2d of August, 1837, where the hurricane increased in violence till half-past seven in the morning, when perfect stillness took place for forty minutes, after which the storm recommenced in a contrary direction.

The sudden fall of the mercury in the barometer in the regions habitually visited by hurricanes is a certain indication of a coming tempest. In consequence of the centrifugal force of these rotatory storms the air becomes rarefied, and as the atmosphere is disturbed to some distance beyond the actual circle of gyration or limits of the storm, the barometer often sinks some hours before its arrival, from the original cause of the rotatory disturbance. It continues sinking under the first half of the hurricane, and again rises during the passage of the latter half, though it does not attain its greatest height till the storm is over. The diminution of atmospheric pressure is greater and extends over a wider area in the temperate zones than in the torrid, on account of the sudden expansion of the circle of rotation when the gale crosses the tropic.

As the fall of the barometer gives warning of the approach of a hurricane, so the laws of the storm's motion afford to the seaman the knowledge to guide him in avoiding it. In the northern temperate zone, if the gale begins from the S. E. and veers by S. to W., the ship

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should steer to the S. E.; but if the gale begins from the N. E., and changes through N. to N. W., the vessel should go to the N. W. In the northern part of the torrid zone, if the storm begin from the N. E. and veer through E. to S. E., the ship should steer to the N. E.; but if it begin from the N. W. and veer by W. to S. W., the ship should steer to the S. W., because she is in the south-western side of the storm. Since the laws of storms are reversed in the southern hemisphere, the rules for steering vessels are necessarily reversed also. A heavy swell is peculiarly characteristic of these storms. In the open sea the swell often extends many leagues beyond the range of the gale which produced it.

Waterspouts are occasioned by small whirlwinds, which always have their origin at a great distance from that part of the sea from which the spout begins to rise, where it is generally calm. The whirl of the air begins in the clouds, and extending downward to the sea, causes the water to ascend in a spiral by the impulse of the centrifugal force. When waterspouts have a progressive motion, the vortex of air in the cloud above must move with the same velocity, otherwise the spouts break, which frequently happens.

Section XVI.

Sound—Propagation of Sound illustrated by a Field of Standing Corn—Nature of Waves—Propagation of Sound through the Atmosphere—Intensity — Noises — A Musical Sound — Quality — Pitch — Extent of Human Hearing—Velocity of Sound in Air, Water, and Solids—Causes of the Obstruction of Sound—Law of its Intensity—Reflection of Sound—Echoes—Thunder—Refraction of Sound—Interference of Sounds.

One of the most important uses of the atmosphere is the conveyance of sound. Without the air deathlike silence would prevail through nature, for in common with all substances it has a tendency to impart vibrations to bodies in contact with it. Therefore undulations received by the air, whether it be from a sudden impulse such as an explosion or the vibrations of a musical chord, are propagated in every direction, and produce the sensation of sound upon the auditory nerves. A bell rung under the exhausted receiver of an air-pump is inaudi-

ble, which shows that the atmosphere is really the me-
dium of sound. In the small undulations of deep water
in a calm, the vibrations of the liquid particles are made
in the vertical plane, that is up and down, or at right
angles to the direction of the transmission of the waves.
But the vibrations of the particles of air which produce
sound differ from these, being performed in the same
direction in which the waves of sound travel. The
propagation of sound has been illustrated by a field of
corn agitated by the wind. However irregular the
motion of the corn may seem on a superficial view, it
will be found, if the velocity of the wind be constant,
that the waves are all precisely similar and equal, and
that all are separated by equal intervals and move in
equal times.

A sudden blast depresses each ear equally and suc-
cessively in the direction of the wind, but in conse-
quence of the elasticity of the stalks and the force of
the impulse, each ear not only rises again as soon as
the pressure is removed, but bends back nearly as
much in the contrary direction, and then continues to
oscillate backward and forward in equal times, like a
pendulum to a less and less extent, till the resistance of
the air puts a stop to the motion. These vibrations are
the same for every individual ear of corn. Yet as their
oscillations do not all commence at the same time, but
successively, the ears will have a variety of positions at
any one instant. Some of the advancing ears will meet
others in their returning vibrations, and as the times of
oscillation are equal for all, they will be crowded to-
gether at regular intervals. Between these there will
occur equal spaces, where the ears will be few, in con-
sequence of being bent in opposite directions; and at
other equal intervals they will be in their natural upright
positions. So that over the whole field there will be a
regular series of condensations and rarefactions among
the ears of corn, separated by equal intervals where
they will be in their natural state of density. In con-
sequence of these changes the field will be marked by
an alternation of bright and dark bands. Thus the
successive waves which fly over the corn with the
speed of the wind, are totally distinct from, and entirely

independent of the extent of the oscillations of each in-
dividual ear, though both take place in the same direc-
tion.   The length of a wave is equal to the space be-
tween two ears precisely in the same state of motion,
or which are moving similarly, and the time of the vi-
bration of each ear is equal to that which elapses be-
tween the arrival of two successive waves at the same
point.   The only difference between the undulations of
a corn-field and those of the air which produce sound
is, that each ear of corn is set in motion by an external
cause and is uninfluenced by the motion of the rest;
whereas in air, which is a compressible and elastic fluid,
when one particle begins to oscillate, it communicates
its vibrations to the surrounding particles, which trans-
mit them to those adjacent, and so on continually.
Hence from the successive vibrations of the particles of
air the same regular condensations and rarefactions take
place as in the field of corn, producing waves through-
out the whole mass of air, though each molecule, like
each individual ear of corn, never moves far from its
state of rest.   The small waves of a liquid and the un-
dulations of the air like waves in the corn, are evidently
not real masses moving in the direction in which they
are advancing, but merely outlines, motions, or forms
passing along, and comprehending all the particles of an
undulating fluid which are at once in a vibratory state.
It is thus that an impulse given to any one point of the
atmosphere is successively propagated in all directions,
in a wave diverging as from the center of a sphere to
greater and greater distances, but with decreasing in-
tensity, in consequence of the increasing number of par-
ticles of inert matter which the force has to move; like
the waves formed in still water by a falling stone, which
are propagated circularly all around the center of dis-
turbance (N. 156).

The intensity of sound depends upon the violence
and extent of the initial vibrations of air; but whatever
they may be, each undulation when once formed can
only be transmitted straight forward, and never returns
back again unless when reflected by an opposing ob-
stacle.   The vibrations of the aërial molecules are al-
ways extremely small, whereas the waves of sound

vary from a few inches to several feet.   The various
musical instruments, the human voice and that of ani-
mals, the singing of birds, the hum of insects, the roar
of the cataract, the whistling of the wind, and the other
nameless peculiarities of sound, show at once an infinite
variety in the modes of aërial vibration, and the aston-
ishing acuteness and delicacy of the ear, thus capable of
appreciating the minutest differences in the laws of
molecular oscillation.

All mere noises are occasioned by irregular impulses
communicated to the ear, and if they be short, sudden,
and repeated beyond a certain degree of quickness, the
ear loses the intervals of silence and the sound appears
continuous.   Still such sounds will be mere noise : in
order to produce a musical sound, the impulses, and
consequently the undulations of the air must be all ex-
actly similar in duration and intensity, and must recur
after exactly equal intervals of time.   If a blow be given
to the nearest of a series of broad, flat, and equidistant
palisades set edgewise in a line direct from the ear,
each palisade will repeat or echo the sound ; and these
echoes returning to the ear at successive equal intervals
of time will produce a musical note.   The quality of a
musical note depends upon the abruptness, and its in-
tensity upon the violence and extent of the original im-
pulse.   In the theory of harmony the only property of
sound taken into consideration is the pitch, which varies
with the rapidity of the vibrations.   The grave or low
tones are produced by very slow vibrations, which in-
crease in frequency as the note becomes more acute.
Very deep tones are not heard by all alike, and Dr. Wol-
laston, who made a variety of experiments on the sense
of hearing, found that many people though not at all
deaf are quite insensible to the cry of the bat or the
cricket, while to others it is painfully shrill.   From his
experiments he concluded that human hearing is limited
to about nine octaves, extending from the lowest note of
the organ to the highest known cry of insects ; and he
observes with his usual originality that, " as there is
nothing in the nature of the atmosphere to prevent the
existence of vibrations incomparably more frequent than
any of which we are conscious, we may imagine that

animals like the Grylli, whose powers appear to commence nearly where ours terminate, may have the faculty of hearing still sharper sounds which we do not know to exist, and that there may be other insects hearing nothing in common with us, but endowed with a power of exciting, and a sense which perceives vibrations of the same nature indeed as those which constitute our ordinary sounds, but so remote that the animals who perceive them may be said to possess another sense, agreeing with our own solely in the medium by which it is excited.

M. Savart, so well known for the number and beauty of his researches in acoustics, has proved that a high note of a given intensity being heard by some ears and not by others, must not be attributed to its pitch, but to its feebleness. His experiments, and those more recently made by Professor Wheatstone, show, that if the pulses could be rendered sufficiently powerful, it would be difficult to fix a limit to human hearing at either end of the scale. M. Savart had a wheel made about nine inches in diameter with 360 teeth set at equal distances round its rim, so that while in motion each tooth successively hit on a piece of card. The tone increased in pitch with the rapidity of the rotation, and was very pure when the number of strokes did not exceed three or four thousand in a second, but beyond that it became feeble and indistinct. With a wheel of a larger size a much higher tone could be obtained, because the teeth being wider apart the blows were more intense and more separated from one another. With 720 teeth on a wheel thirty-two inches in diameter, the sound produced by 12,000 strokes in a second was audible, which corresponds to 24,000 vibrations of a musical chord. So that the human ear can appreciate a sound which only lasts the 24,000th part of a second. This note was distinctly heard by M. Savart and by several people who were present, which convinced him that with another apparatus still more acute sounds might be rendered audible.

For the deep tones M. Savart employed a bar of iron, two feet eight inches long, about two inches broad, and half an inch in thickness, which revolved about its center

as if its arms were the spokes of a wheel. When such a machine rotates it impresses a motion on the air similar to its own, and when a thin board or card is brought close to its extremities, the current of air is momentarily interrupted at the instant each arm of the bar passes before the card; it is compressed above the card and dilated below; but the instant the spoke has passed, a rush of air to restore equilibrium makes a kind of explosion, and when these succeed each other rapidly, a musical note is produced of a pitch proportional to the velocity of the revolution. When M. Savart turned this bar slowly a succession of single beats was heard; as the velocity became greater the sound was only a rattle; but as soon as it was sufficient to give eight beats in a second, a very deep musical note was distinctly audible, corresponding to sixteen single vibrations in a second, which is the lowest that has hitherto been produced. When the velocity of the bar was much increased the intensity of the sound was hardly bearable. The spokes of a revolving wheel produce the sensation of sound, on the very same principle that a burning stick whirled round gives the impression of a luminous circle. The vibrations excited in the organ of hearing by one beat have not ceased before another impulse is given. Indeed it is indispensable that the impressions made upon the auditory nerves should encroach upon each other in order to produce a full and continued note. On the whole, M. Savart has come to the conclusion, that the most acute sounds would be heard with as much ease as those of a lower pitch, if the duration of the sensation produced by each pulse could be diminished proportionally to the augmentation of the number of pulses in a given time: and on the contrary, if the duration of the sensation produced by each pulse could be increased in proportion to their number in a given time, that the deepest tones would be as audible as any of the others.

The velocity of sound is uniform and independent of the nature, extent, and intensity of the primitive disturbance. Consequently sounds of every quality and pitch travel with equal speed. The smallest difference in their velocity is incompatible either with harmony or melody, for notes of different pitches and intensities

sounded together at a little distance, would arrive at the
ear in different times. A rapid succession of notes
would in this case produce confusion and discord. But
as the rapidity with which sound is transmitted depends
upon the elasticity of the medium through which it has
to pass, whatever tends to increase the elasticity of the
air must also accelerate the motion of sound. On that
account its velocity is greater in warm than in cold
weather, supposing the pressure of the atmosphere con-
stant. In dry air at the freezing temperature, sound
travels at the rate of 1090 feet in a second, and for any
higher temperature one foot must be added for every
degree of the thermometer above 32° ; hence at 62° of
Fahrenheit its speed in a second is 1120 feet, or 765
miles an hour, which is about three-fourths of the diur-
nal velocity of the earth's equator. Since all the phe-
nomena of the transmission of sound are simple conse-
quences of the physical properties of the air, they have
been predicted and computed rigorously by the laws of
mechanics. It was found, however, that the velocity of
sound determined by observation, exceeded what it ought
to have been theoretically by 173 feet, or about one-sixth
of the whole amount. La Place suggested that this dis-
crepancy might arise from the increased elasticity of the
air in consequence of a development of latent heat (N.
173) during the undulations of sound, and calculation
confirmed the accuracy of his views. The aërial mole-
cules being suddenly compressed give out their latent
heat ; and as air is too bad a conductor to carry it rap-
idly off, it occasions a momentary and local rise of tem-
perature which, increasing the elasticity of the air
without at the same time increasing its inertia, causes
the movement to be propagated more rapidly. Analysis
gives the true velocity of sound in terms of the elevation
of temperature that a mass of air is capable of commu-
nicating to itself, by the disengagement of its own latent
heat when suddenly compressed in a given ratio. This
change of temperature however could not be obtained
directly by any experiments which had been made at
that epoch ; but by inverting the problem and assuming
the velocity of sound as given by experiment, it was
computed that the temperature of a mass of air is raised

nine-tenths of a degree when the compression is equal to $\frac{1}{118}$ of its volume.

Probably all liquids are elastic, though considerable force is required to compress them. Water suffers a condensation of nearly 0·0000496 for every atmosphere of pressure, and is consequently capable of conveying sound even more rapidly than air, the velocity in the former being 4708 feet in a second. A person under water hears sounds made in air feebly, but those produced in water very distinctly. According to the experiments of M. Colladon, the sound of a bell was conveyed under water through the Lake of Geneva to the distance of about nine miles. He also perceived that the progress of sound through water is greatly impeded by the interposition of any object, such as a projecting wall; consequently sound under water resembles light in having a distinct shadow. It has much less in air, being transmitted all round buildings or other obstacles, so as to be heard in every direction, though often with a considerable diminution of intensity, as when a carriage turns the corner of a street.

The velocity of sound in passing through solids is in proportion to their hardness, and is much greater than in air or water. A sound which takes some time in traveling through the air passes almost instantaneously along a wire six hundred feet long; consequently it is heard twice—first as communicated by the wire and afterward through the medium of the air. The facility with which the vibrations of sound are transmitted along the grain of a log of wood is well known. Indeed they pass through iron, glass, and some kinds of wood, at the rate of 18,530 feet in a second. The velocity of sound is obstructed by a variety of circumstances, such as falling snow, fog, rain, or any other cause which disturbs the homogeneity of the medium through which it has to pass. M. de Humboldt says that it is on account of the greater homogeneity of the atmosphere during the night that sounds are then better heard than during the day, when its density is perpetually changing from partial variations of temperature. His attention was called to this subject on the plain surrounding the Mission of the Apures by the rushing noise of the great cataracts

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of the Oronoco, which seemed to be three times as loud by night as by day. This he illustrated by experiment. A tall glass half full of champaigne cannot be made to ring as long as the effervescence lasts. In order to produce a musical note the glass together with the liquid it contains must vibrate in unison as a system, which it cannot do in consequence of the fixed air rising through the wine and disturbing its homogeneity, because the vibrations of the gas being much slower than those of the liquid the velocity of the sound is perpetually interrupted. For the same reason the transmission of sound as well as light is impeded in passing through an atmosphere of variable density. Sir John Herschel, in his admirable Treatise on Sound, thus explains the phenomenon:—"It is obvious," he says, "that sound as well as light must be obstructed, stifled, and dissipated from its original direction by the mixture of air of different temperatures, and consequently elasticities; and thus the same cause which produces that extreme transparency of the air at night, which astronomers alone fully appreciate, renders it also more favorable to sound. There is no doubt, however, that the universal and dead silence, generally prevalent at night, renders our auditory nerves sensible to impressions which would otherwise escape notice. The analogy between sound and light is perfect in this as in so many other respects. In the general light of day the stars disappear. In the continual hum of voices, which is always going on by day, and which reach us from all quarters and never leave the ear time to attain complete tranquillity, those feeble sounds which catch our attention at night make no impression. The ear, like the eye, requires long and perfect repose to attain its utmost sensibility."

Many instances may be brought in proof of the strength and clearness with which sound passes over the surface of water or ice. Lieutenant Foster was able to carry on a conversation across Fort Bowen harbor, when frozen, a distance of a mile and a half.

The intensity of sound depends upon the extent of the excursions of the fluid molecules, on the energy of the transient condensations and dilatations, and on the greater or less number of particles which experience

these effects. We estimate that intensity by the im-
petus of these fluid molecules on our organs, which is
consequently as the square of the velocity, and not by
their inertia, which is as the simple velocity. Were
the latter the case there would be no sound, because the
inertia of the receding waves of air would destroy the
equal and opposite inertia of those advancing; whence
it may be concluded that the intensity of sound dimin-
ishes inversely as the square of the distance from its
origin. In a tube, however, the force of sound does
not decay as in open air, unless perhaps by friction
against the sides. M. Biot found from a number of
highly interesting experiments made on the pipes of the
aqueducts in Paris, that a continual conversation could
be carried on in the lowest possible whisper, through
a cylindrical tube about 3120 feet long, the time of
transmission through that space being 2·79 seconds. In
most cases sound diverges in all directions so as to oc-
cupy at any one time a spherical surface; but Dr. Young
has shown that there are exceptions, as for example
when a flat surface vibrates only in one direction. The
sound is then most intense when the ear is at right an-
gles to the surface, whereas it is scarcely audible in a
direction precisely perpendicular to its edge. In this
case it is impossible that the whole of the surrounding
air can be affected in the same manner, since the particles
behind the sounding surface must be moving toward it,
whenever the particles before it are retreating. Hence
in one half of the surrounding sphere of air its motions
are retrogade, while in the other half they are direct ;
consequently at the edges where these two portions
meet, the motions of the air will neither be retrograde
nor direct, and therefore it must be at rest.

It appears from theory as well as daily experience,
that sound is capable of reflection from surfaces (N. 174)
according to the same laws as light. Indeed any one
who has observed the reflection of the waves from a
wall on the side of a river after the passage of a steam-
boat, will have a perfect idea of the reflection of sound
and of light. As every substance in nature is more or
less elastic, it may be agitated according to its own law
by the impulse of a mass of undulating air ; and recip-

interfering, so as to produce nodes; so that the motions
of a string fastened at both ends consists of a wave or
pulse, continually doubled back on itself by reflection at
the fixed extremities.

Harmonics generally coexist with the fundamental
sound in the same vibrating body. If one of the lowest
strings of the piano-forte be struck, an attentive ear
will not only hear the fundamental note, but will detect
all the others sounding along with it, though with less
and less intensity as their pitch becomes higher. Ac-
cording to the law of coexisting undulations, the whole
string and each of its aliquot parts are in different and
independent states of vibration at the same time; and
as all the resulting notes are heard simultaneously, not
only the air but the ear also vibrates in unison with
each at the same instant (N. 176).

Harmony consists in an agreeable combination of
sounds. When two chords perform their vibrations in
the same time, they are in unison. But when their
vibrations are so related as to have a common period
after a few oscillations they produce concord. Thus
when the vibrations of two strings bear a very simple
relation to each other, as where one of them makes
two, three, four, &c. vibrations in the time the other
makes one; or if it accomplishes three, four, &c. vibra-
tions while the other makes two, the result is a concord
which is the more perfect the shorter the common
period. In discords, on the contrary, the beats are
distinctly audible, which produces a disagreeable and
harsh effect, because the vibrations do not bear a simple
relation to one another, as where one of two strings
makes eight vibrations while the other accomplishes
fifteen. The pleasure afforded by harmony is attributed
by Dr. Young to the love of order, and to a predilection
for a regular repetition of sensations natural to the
human mind, which is gratified by the perfect regularity
and rapid recurrence of the vibrations. The love of
poetry and dancing he conceives to arise in some degree
from the rhythm of the one and the regularity of the
motions in the other.

A blast of air passing over the open end of a tube, as
over the reeds in Pan's pipes; over a hole in one side,

as in the flute; or through the aperture called a reed with a flexible tongue, as in the clarinet, puts the internal column of air into longitudinal vibrations by the alternate condensations and rarefactions of its particles. At the same time the column spontaneously divides itself into nodes between which the air also vibrates longitudinally, but with a rapidity inversely proportional to the length of the divisions, giving the fundamental note or one of its harmonics. The nodes are produced on the principle of interferences by the reflection of the longitudinal undulations of the air at the ends of the pipe, as in the musical string, only that in one case the undulations are longitudinal, and in the other transverse.

A pipe either open or shut at both ends when sounded vibrates entire, or divides itself spontaneously into two, three, four, &c. segments separated by nodes. The whole column gives the fundamental note by waves or vibrations of the same length with the pipe. The first harmonic is produced by waves half as long as the tube, the second harmonic by waves a third as long, and so on. The harmonic segments in an open and shut pipe are the same in number, but differently placed. In a shut pipe the two ends are nodes, but in an open pipe there is half a segment at each extremity, because the air at these points is neither rarefied nor condensed, being in contact with that which is external. If one of the ends of the open pipe be closed, its fundamental note will be an octave lower, the air will now divide itself into three, five, seven, &c. segments; and the wave producing its fundamental note will be twice as long as the pipe, so that it will be doubled back (N. 177). All these notes may be produced separately, by varying the intensity of the blast. Blowing steadily and gently, the fundamental note will sound; when the force of the blast is increased, the note will all at once start up an octave; when the intensity of the wind is augmented, the twelfth will be heard, and by continuing to increase the force of the blast the other harmonics may be obtained, but no force of wind will produce a note intermediate between these. The harmonics of a flute may be obtained in this manner, from the lowest C or D upward, without altering the fingering, merely

by increasing the intensity of the blast, and altering the
form of the lips.   Pipes of the same dimensions,
whether of lead, glass, or wood, give the same tone as to
pitch under the same circumstances, which shows that
the air alone produces the sound.

Metal springs fastened at one end, when forcibly
bent, endeavor to return to rest by a series of vibrations,
which give very pleasing tones, as in musical boxes.
Various musical instruments have recently been con-
structed, consisting of metallic springs thrown into vibra-
tion by a current of air.   Among the most perfect of these
are Mr. Wheatstone's Symphonion, Concertina, and Æo-
lian Organ, instruments of different effects and capabilities,
but all possessing considerable execution and expression.

The Syren is an ingenious instrument, devised by M.
Cagniard de la Tour, for ascertaining the number of
pulsations in a second corresponding to each pitch : the
notes are produced by jets of air passing through small
apertures arranged at regular distances in a circle on
the side of a box, before which a disc revolves pierced
with the same number of holes.   During a revolution
of the disc the currents are alternately intercepted and
allowed to pass as many times as there are apertures ir
it, and a sound is produced whose pitch depends on the
velocity of rotation.

A glass or metallic rod, when struck at one end, or
rubbed in the direction of its length with a wet finger,
vibrates longitudinally like a column of air, by the alter-
nate condensation and expansion of its constituent par-
ticles, producing a clear and beautiful musical note of
a high pitch, on account of the rapidity with which
these substances transmit sound.   Rods, surfaces, and,
in general, all undulating bodies, resolve themselves into
nodes.   But in surfaces, the parts which remain at rest
during their vibrations are lines, which are curved or
plane according to the substance, its form, and the mode
of vibration. If a little fine dry sand be strewed over
the surface of a plate of glass or metal, and if undula-
tions be excited by drawing the bow of a violin across
its edge, it will emit a musical sound, and the sand
will immediately arrange itself in the nodal lines, where
alone it will accumulate and remain at rest, because the

segments of the surface on each side will be in different states of vibration, the one being elevated while the other is depressed; and as these two motions meet in the nodal lines, they neutralize one another. These lines vary in form and position with the part where the bow is drawn across, and the point by which the plate is held. The motion of the sand shows in what direction the vibrations take place. If they be perpendicular to the surface, the sand will be violently tossed up and down, till it finds the points of rest. If they be tangential, the sand will only creep along the surface to the nodal lines. Sometimes the undulations are oblique, or compounded of both the preceding. If a bow be drawn across one of the angles of a square plate of glass or metal held firmly by the center, the sand will arrange itself in two straight lines parallel to the sides of the plate, and crossing in the center so as to divide it into four equal squares, whose motions will be contrary to each other. Two of the diagonal squares will make their excursions on one side of the plate, while the other two make their vibrations on the other side of it. This mode of vibration produces the lowest tone of the plate (N. 178). If the plate be still held by the center, and the bow applied to the middle of one of the sides, the vibrations will be more rapid, and the tone will be a fifth higher than in the preceding case; now the sand will arrange itself from corner to corner, and will divide the plate into four equal triangles, each pair of which will make their excursions on opposite sides of the plate. The nodal lines and pitch vary not only with the point where the bow is applied, but with the point by which the plate is held, which being at rest, necessarily determines the direction of one of the quiescent lines. The forms assumed by the sand in square plates are very numerous, corresponding to all the various modes of vibration. The lines in circular plates are even more remarkable for their symmetry, and upon them the forms assumed by the sand may be classed in three systems. The first is the diametrical system, in which the figures consist of diameters dividing the circumference of the plate into equal parts, each of which is in a different state of vibration from

those adjacent. Two diameters, for example, crossing at right angles, divide the circumference into four equal parts; three diameters divide it into six equal parts; four divide it into eight, and so on. In a metallic plate, these divisions may amount to thirty-six or forty. The next is the concentric system, where the sand arranges itself in circles, having the same center with the plate; and the third is the compound system, where the figures assumed by the sand are compounded of the other two, producing very complicated and beautiful forms. Galileo seems to have been the first to notice the points of rest and motion in the sounding-board of a musical instrument; but to Chladni is due the whole discovery of the symmetrical forms of the nodal lines in vibrating plates (N. 179). Professor Wheatstone has shown in a paper read before the Royal Society, in 1833, that all Chladni's figures, and indeed all the nodal figures of vibrating surfaces, result from very simple modes of vibration, oscillating isochronously, and superposed upon each other; the resulting figure varying with the component modes of vibration, the number of the superpositions, and the angles at which they are superposed. For example, if a square plate be vibrating so as to make the sand arrange itself in straight lines parallel to one side of the plate, and if, in addition to this, such vibrations be excited as would have caused the sand to form in lines perpendicular to the first had the plate been at rest, the combined vibrations will make the sand form in lines from corner to corner (N. 180).

M. Savart's experiments on the vibrations of flat glass rulers are highly interesting. Let a lamina of glass $27^{in}\cdot56$ long, $0\cdot59$ of an inch broad, $0\cdot06$ of an inch in thickness, be held by the edges in the middle, with its flat surface horizontal. If this surface be strewed with sand, and set in longitudinal vibration by rubbing its under surface with a wet cloth, the sand on the upper surface will arrange itself in lines parallel to the ends of the lamina, always in one or other of two systems (N. 181). Although the same one of the two systems will always be produced by the same plate of glass, yet among different plates of the preceding dimensions, even though cut from the same sheet side by side, one will

invariably exhibit one system, and the other the other, without any visible reason for the difference. Now if the positions of these quiescent lines be marked on the upper surface, and if the plate be turned so that the lower surface becomes the upper one, the sand being strewed, and vibrations excited as before, the nodal lines will still be parallel to the ends of the lamina, but their positions will be intermediate between those of the upper surface (N. 182). Thus it appears that all the motions of one half of the thickness of the lamina, or ruler, are exactly contrary to those of the corresponding points of the other half. If the thickness of the lamina be increased, the other dimensions remaining the same, the sound will not vary, but the number of nodal lines will be less. When the breadth of the lamina exceeds the 0·6 of an inch, the nodal lines become curved and are different on the two surfaces. A great variety of forms are produced by increasing the breadth and changing the form of the surface; but in all, it appears that the motions in one half of the thickness are opposed to those in the other half.

M. Savart also found, by placing small paper rings round a cylindrical tube or rod, so as to rest upon it at one point only, that when the tube or rod is continually turned on its axis in the same direction, the rings slide along during the vibrations, till they come to a quiescent point, where they rest. By tracing these nodal lines he discovered that they twist in a spiral or corkscrew round rods and cylinders, making one or more turns according to the length; but at certain points, varying in number according to the mode of vibration of the rod, the screw stops, and recommences on the other side, though it is turned in a contrary direction; that is, on one side it is a right-handed screw, on the other a left (N. 183). The nodal lines in the interior surface of the tubes are perfectly similar to those in the exterior, but they occupy intermediate positions. If a small ivory ball be put within the tube, it will follow these nodal lines when the tube is made to revolve on its axis.

All solids which ring when struck, such as bells, drinking glasses, gongs, &c., have their shape momentarily and forcibly changed by the blow, and from their

elasticity, or tendency to resume their natural form, a
series of undulations takes place, owing to the alternate
condensations and rarefactions of the particles of solid
matter.   These have also their harmonic tones, and
consequently nodes.   Indeed generally, when a rigid
system of any form whatever vibrates either transverse-
ly or longitudinally, it divides itself into a certain number
of parts, which perform their vibrations without disturb-
ing one another.   These parts are at every instant in
alternate states of undulation; and as the points or lines
where they join partake of both they remain at rest,
because the opposing motions destroy one another.
   The air, notwithstanding its rarity, is capable of trans-
mitting its undulations when in contact with a body sus-
ceptible of admitting and exciting them.   It is thus that
sympathetic undulations are excited by a body vibrating
near insulated tended strings, capable of following its
undulations, either by vibrating entire, or by separating
themselves into their harmonic divisions.   If two chords
equally stretched, of which one is twice or three times
longer than the other, be placed side by side, and if the
shorter be sounded, its vibrations will be communicated
by the air to the other, which will be thrown into such
a state of vibration that it will be spontaneously divided
into segments equal in length to the shorter string.
When a tuning-fork receives a blow and is made to rest
upon a piano-forte during its vibration, every string
which, either by its natural length or by its spontaneous
subdivisions, is capable of executing corresponding vibra-
tions, responds in a sympathetic note.   Some one or
other of the notes of an organ are generally in unison
with one of the panes or with the whole sash of a win-
dow, which consequently resounds when these notes
are sounded.   A peal of thunder has frequently the
same effect.   The sound of very large organ-pipes is
generally inaudible till the air be set in motion by the
undulations of some of the superior accords, and then
its sound becomes extremely energetic.   Recurring vi-
brations occasionally influence each other's periods.   For
example, two adjacent organ-pipes nearly in unison, may
force themselves into concord; and two clocks whose
rates differed considerably when separate, have been

known to beat together when fixed to the same wall, and one clock has forced the pendulum of another into motion, when merely standing on the same stone pavement. These forced oscillations, which correspond in their periods with those of the exciting cause, are to be traced in every department of physical science. Several instances of them have already occurred in this work. Such are the tides, which follow the sun and moon in all their motions and periods. The nutation of the earth's axis also, which corresponds with the period, and represents the motion of the nodes of the moon, is again reflected back to the moon, and may be traced in the nutation of the lunar orbit. And lastly, the acceleration of the moon's mean motion represents the action of the planets on the earth reflected by the sun to the moon.

In consequence of the facility with which the air communicates undulations, all the phenomena of vibrating plates may be exhibited by sand strewed on paper or parchment, stretched over a harmonica glass or large bell-shaped tumbler. In order to give due tension to the paper or vellum, it must be wetted, stretched over the glass, gummed round the edges, allowed to dry, and varnished over to prevent changes in its tension from the humidity of the atmosphere. If a circular disc of glass be held concentrically over this apparatus, with its plane parallel to the surface of the paper, and set in vibration by drawing a bow across its edge, so as to make sand on its surface take any of Chladni's figures, the sand on the paper will assume the very same form, in consequence of the vibrations of the disc being communicated to the paper by the air. When the disc is removed slowly in a horizontal direction, the forms on the paper will correspond with those on the disc, till the distance is too great for the air to convey the vibrations. If the disc while vibrating be gradually more and more inclined to the horizon, the figures on the paper will vary by degrees; and when the vibrating disc is perpendicular to the horizon, the sand on the paper will form into straight lines parallel to the surface of the disc, by creeping along it instead of dancing up and down. If the disc be made to turn round its vertical diameter while vibrating, the nodal lines on the paper will revolve, and exactly follow the

motion of the disc. It appears from this experiment, that the motions of the aërial molecules in every part of a spherical wave, propagated from a vibrating body as a center, are parallel to each other, and not divergent like the radii of a circle. When a slow air is played on a flute near this apparatus, each note calls up a particular form in the sand, which the next note effaces to establish its own. The motion of the sand will even detect sounds that are inaudible. By the vibrations of sand on a drum-head the besieged have discovered the direction in which a counter-mine was working. M. Savart, who made these beautiful experiments, employed this apparatus to discover nodal lines in masses of air. He found that the air of a room, when thrown into undulations by the continued sound of an organ-pipe, or by any other means, divides itself into masses separated by nodal curves of double curvature, such as spirals, on each side of which the air is in opposite states of vibration. He even traced these quiescent lines going out at an open window, and for a considerable distance in the open air. The sand is violently agitated where the undulations of the air are greatest, and remains at rest in the nodal lines. M. Savart observed, that when he moved his head away from a quiescent line toward the right the sound appeared to come from the right, and when he moved it toward the left the sound seemed to come from the left, because the molecules of air are in different states of motion on each side of the quiescent line.

A musical string gives a very feeble sound when vibrating alone, on account of the small quantity of air set in motion. But when attached to a sounding-board, as in the harp and piano-forte, it communicates its undulations to that surface, and from thence to every part of the instrument; so that the whole system vibrates isochronously, and by exposing an extensive undulating surface, which transmits its undulations to a great mass of air, the sound is much reinforced. The intensity is greatest when the vibrations of the string or sounding body are perpendicular to the sounding-board, and least when they are in the same plane with it. The sounding-board of the piano-forte is better disposed than that of any other stringed instrument, because the hammers

strike the strings so as to make them vibrate at right
angles to it. In the guitar, on the contrary, they are
struck obliquely, which renders the tone feeble, unless
when the sides, which also act as a sounding-board, are
deep. It is evident that the sounding-board and the
whole instrument are agitated at once by all the super-
posed vibrations excited by the simultaneous or consecu-
tive notes that are sounded, each having its perfect effect
independently of the rest. A sounding-board not only
reciprocates the different degrees of pitch, but all the
nameless qualities of tone. This has been beautifully
illustrated by Professor Wheatstone in a series of exper-
iments on the transmission through solid conductors of
musical performances, from the harp, piano, violin, clar-
inet, &c. He found that all the varieties of pitch, qual-
ity, and intensity, are perfectly transmitted with their
relative gradations, and may be communicated through
conducting wires or rods of very considerable length, to
a properly disposed sounding-board in a distant apart-
ment. The sounds of an entire orchestra may be trans-
mitted and reciprocated by connecting one end of a
metallic rod with a sounding-board near the orchestra,
so placed as to resound to all the instruments, and the
other end with the sounding-board of a harp, piano, or
guitar, in a remote apartment. Professor Wheatstone
observes, " The effect of this experiment is very pleas-
ing; the sounds, indeed, have so little intensity as scarcely
to be heard at a distance from the reciprocating instru-
ment ; but on placing the ear close to it, a diminutive
band is heard, in which all the instruments preserve
their distinctive qualities, and the pianos and fortes, the
crescendos and diminuendos, their relative contrasts.
Compared with an ordinary band heard at a distance
through the air, the effect is as a landscape seen in min-
iature beauty through a concave lens, compared with
the same scene viewed by ordinary vision through a
murky atmosphere."
     Every one is aware of the reinforcement of sound by
the resonance of cavities. When singing or speaking
near the aperture of a wide-mouthed vessel, the inten-
sity of some one note in unison with the air in the cav-
ity, is often augmented to a great degree. Any vessel
     10   N

will resound if a body vibrating the natural note of the cavity be placed opposite to its orifice, and be large enough to cover it; or at least to set a large portion of the adjacent air in motion. For the sound will be alternately reflected by the bottom of the cavity and the undulating body at its mouth. The first impulse of the undulating substance will be reflected by the bottom of the cavity, and then by the undulating body, in time to combine with the second new impulse. This reinforced sound will also be twice reflected in time to conspire with the third new impulse; and as the same process will be repeated on every new impulse, each will combine with all its echoes to reinforce the sound prodigiously. Professor Wheatstone, to whose ingenuity we are indebted for so much new and valuable information on the theory of sound, has given some very striking instances of resonance. If one of the branches of a vibrating tuning-fork be brought near the embouchure of a flute, the lateral apertures of which are stopped so as to render it capable of producing the same sound as the fork, the feeble and scarcely audible sound of the fork will be augmented by the rich resonance of the column of air within the flute, and the tone will be full and clear. The sound will be found greatly to decrease by closing or opening another aperture; for the alteration in the length of the column of air renders it no longer fit perfectly to reciprocate the sound of the fork. This experiment may be made on a concert flute with a C tuning-fork. But Professor Wheatstone observes, that in this case it is generally necessary to finger the flute for B, because when blown into with the mouth the under-lip partly covers the embouchure, which renders the sound about a semitone flatter than it would be were the embouchure entirely uncovered. He has also shown, by the following experiment, that any one among several simultaneous sounds may be rendered separately audible. If two bottles be selected, and tuned by filling them with such a quantity of water as will render them unisonant with two tuning-forks which differ in pitch, on bringing both of the vibrating tuning-forks to the mouth of each bottle alternately, in each case that sound only will be heard which is reciprocated by the unisonant bottle.

Several attempts have been made to imitate the artic-
ulation of the letters of the alphabet. About the year
1779, MM. Kratzenstein of St. Petersburgh, and Kem-
pelen of Vienna, constructed instruments which articu-
lated many letters, words, and even sentences. Mr.
Willis of Cambridge has recently adapted cylindrical
tubes to a reed, whose length can be varied at pleasure
by sliding joints. Upon drawing out a tube while a col-
umn of air from the bellows of an organ is passing
through it, the vowels are pronounced in the order, *i, e,
a, o, u,* On extending the tube they are repeated after
a certain interval, in the inverted order, *u, o, a, e, i.* Af-
ter another interval they are again obtained in the direct
order, and so on. When the pitch of the reed is very
high, it is impossible to sound some of the vowels, which
is in perfect correspondence with the human voice, fe-
male singers being unable to pronounce *u* and *o* in their
high notes. From the singular discoveries of M. Savart
on the nature of the human voice, and the investiga-
tions of Mr. Willis on the mechanism of the larynx,
it may be presumed that ultimately the utterance or
pronunciation of modern languages will be conveyed,
not only to the eye but also to the ear of posterity.
Had the ancients possessed the means of transmitting
such definite sounds, the civilized world would still have
responded in sympathetic notes at the distance of many
ages.

SECTION XVIII.

Refraction—Astronomical Refraction and its Laws—Formation of Tables of
　Refraction—Terrestrial Refraction—Its Quantity—Instances of Extraor-
　dinary Refraction—Reflection—Instances of Extraordinary Reflection—
　Loss of Light by the Absorbing Power of the Atmosphere—Apparent
　Magnitude of Sun and Moon in the Horizon.

NOT only everything we hear but all we see is through
the medium of the atmosphere. Without some knowl-
edge of its action upon light, it would be impossible to
ascertain the position of the heavenly bodies, or even to
determine the exact place of very distant objects upon
the surface of the earth; for in consequence of the re-

fractive power of the air, no distant object is seen in its true position.

All the celestial bodies appear to be more elevated than they really are ; because the rays of light, instead of moving through the atmosphere in straight lines, are continually inflected toward the earth. Light passing obliquely out of a rare into a denser medium, as from vacuum into air, or from air into water, is bent or re- fracted from its course toward a perpendicular to that point of the denser surface where the light enters it (N. 184). In the same medium, the sine of the angle contained between the incident ray and the perpendic- ular is in a constant ratio to the sine of the angle con- tained by the refracted ray and the same perpendicu- lar ; but this ratio varies with the refracting medium. The denser the medium the more the ray is bent. The barometer shows that the density of the atmos- phere decreases as the height above the earth increases. Direct experiments prove that the refractive power of the air increases with its density. It follows therefore that if the temperature be uniform, the refractive power of the air is greatest at the earth's surface and dimin- ishes upward.

A ray of light from a celestial object falling obliquely on this variable atmosphere, instead of being refracted at once from its course, is gradually more and more bent during its passage through it so as to move in a vertical curved line, in the same manner as if the atmosphere consisted of an infinite number of strata of different den- sities.   The object is seen in the direction of a tangent to that part of the curve which meets the eye, conse- quently the apparent altitude (N. 185) of the heavenly bodies is always greater than their true altitude.   Owing to this circumstance, the stars are seen above the hori- zon after they are set, and the day is lengthened from a part of the sun being visible, though he really is behind the rotundity of the earth. It would be easy to de- termine the direction of a ray of light through the at- mosphere if the law of the density were known ; but as this law is perpetually varying with the temperature, the case is very complicated. When rays pass perpen- *dicularly from one* medium into another, they are not

when of glass or platina. When the rays which form
the fringes arrive at the screen, they are of different
lengths, in consequence of the curved path they follow
after passing the edge of the object. The waves are
therefore in different phases or states of vibration, and
either conspire to form colored fringes or destroy one
another in the obscure intervals. The colored fringes
bordering the shadows of objects were first described by
Grimaldi in 1665; but besides these he noticed that
there are others within the shadows of slender bodies
exposed to a small sunbeam, a phenomenon which has
already been mentioned to have afforded Dr. Young the
means of proving beyond all controversy, that colored
rings are produced by the interference of light.

It may be concluded, that material substances derive
their colors from two different causes: some from the
law of interference, such as iridescent metals, peacocks'
feathers, &c.; others from the unequal absorption of
the rays of white light, such as vermilion, ultramarine,
blue, or green cloth, flowers, and the greater number of
colored bodies. The latter phenomena have been con-
sidered extremely difficult to reconcile with the undula-
tory theory of light, and much discussion has arisen as
to what becomes of the absorbed rays. But that em-
barrassing question has been ably answered by Sir John
Herschel in a most profound paper, On the Absorption
of Light by colored Media, and cannot be better given
than in his own words. It must however be premised,
that as all transparent bodies are traversed by light,
they are presumed to be permeable to the ether. He
says, " Now, as regards only the general fact of the ob-
struction and ultimate extinction of light in its passage
through gross media, if we compare the corpuscular and
undulatory theories, we shall find that the former ap-
peals to our ignorance, the latter to our knowledge, for
its explanation of the absorptive phenomena. In at-
tempting to explain the extinction of light on the corpus-
cular doctrine, we have to account for the light so extin-
guished as a material body, which we must not suppose
annihilated. It may however be transformed; and
among the imponderable agents, heat, electricity, &c.,
it may be that we are to search for the light which has

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become thus comparatively stagnant. The heating power of the solar rays gives a *primâ facie* plausibility to the idea of the transformation of light into heat by absorption. But when we come to examine the matter more nearly, we find it encumbered on all sides with difficulties. How is it, for instance, that the most luminous rays are not the most calorific; but that on the contrary, the calorific energy accompanies, in its greatest intensity, rays which possess comparatively feeble illuminating powers? These and other questions of a similar nature may perhaps admit of answer in a more advanced state of our knowledge; but at present there is none obvious. It is not without reason, therefore, that the question 'What becomes of light?' which appears to have been agitated among the photologists of the last century, has been regarded as one of considerable importance as well as obscurity by the corpuscular philosophers. On the other hand, the answer to this question, afforded by the undulatory theory of light, is simple and distinct. The question, 'What becomes of light?' merges in the more general one, 'What becomes of motion?' And the answer, on dynamical principles, is, that it continues forever. No motion is, strictly speaking, annihilated; but it may be divided, and the divided parts made to oppose and, *in effect*, destroy one another. A body struck, however perfectly elastic, vibrates for a time, and then appears to sink into its original repose. But this apparent rest (even abstracting from the inquiry that part of the motion which may be conveyed away by the ambient air) is nothing else than a state of subdivided and mutually destroying motion, in which every molecule continues to be agitated by an indefinite multitude of internally reflected waves, propagated through it in every possible direction, from every point in its surface on which they successively impinge. The superposition of such waves will, it is easily seen, at length operate their mutual destruction, which will be the more complete the more irregular the figure of the body, and the greater the number of internal reflections." Thus Sir John Herschel, by referring the absorption of light to the subdivision and mutual destruction of the vibrations of ether in the interior of

temperature which are not so soon communicated to the water on account of its density as to the air, occur more rarely and are of shorter duration than similar appearances on land. In 1818, Captain Scoresby, whose observations on the phenomena of the polar seas are so valuable, recognized his father's ship by its inverted image in the air, although the vessel itself was below the horizon. He afterward found that she was seventeen miles beyond the horizon, and thirty miles distant. Two images are sometimes seen suspended in the air over a ship, one direct and the other inverted, with their topmasts or their hulls meeting, according as the inverted image is above or below the direct image (N. 188). Dr. Wollaston has proved that these appearances are owing to the refraction of the rays through media of different densities, by the very simple experiment of looking along a red-hot poker at a distant object. Two images are seen, one direct and another inverted, in consequence of the change induced by the heat in the density of the adjacent air. He produced the same effect by a saline or saccharine solution with water and spirit of wine floating upon it (N. 189).

Many of the phenomena that have been ascribed to extraordinary refraction seem to be occasioned by a partial or total reflection of the rays of light at the surfaces of strata of different densities (N. 184). It is well known that when light falls obliquely upon the external surface of a transparent medium, as on a plate of glass or stratum of air, one portion is reflected and the other transmitted. But when light falls very obliquely upon the internal surface, the whole is reflected and not a ray is transmitted. In all cases the angles made by the incident and reflected rays with a perpendicular to the surface being equal, as the brightness of the reflected image depends on the quantity of light, those arising from total reflection must be by far the most vivid. The delusive appearance of water, so well known to African travelers and to the Arab of the desert as the Lake of the Gazelles, is ascribed to the reflection which takes place between strata of air of different densities, owing to radiation of heat from the arid sandy plains. The mirage described by Captain

Mundy in his Journal of a Tour in India probably
arises from this cause. A deep precipitous valley be-
low us, at the bottom of which I had seen one or two
miserable villages in the morning, bore in the evening a
complete resemblance to a beautiful lake; the vapor
which played the part of water ascending nearly half
way up the sides of the vale, and on its bright surface
trees and rocks being distinctly reflected. I had not
been long contemplating this phenomenon, before a
sudden storm came on and dropped a curtain of clouds
over the scene."

An occurrence which happened on the 18th of No-
vember, 1804, was probably produced by reflection.
Dr. Buchan, while watching the rising sun from the
cliff about a mile to the east of Brighton, at the instant
the solar disc emerged from the surface of the ocean,
saw the cliff on which he was standing, a windmill, his
own figure and that of a friend, depicted immediately
opposite to him on the sea. This appearance lasted
about ten minutes, till the sun had risen nearly his own
diameter above the surface of the waves. The whole
then seemed to be elevated into the air and successively
vanished. The rays of the sun fell upon the cliff at an
incidence of 73° from the perpendicular, and the sea
was covered with a dense fog many yards in height
which gradually receded before the rising sun. When
extraordinary refraction takes place laterally, the strata
of variable density are perpendicular to the horizon,
and if combined with vertical refraction, the objects
are magnified as when seen through a telescope. From
this cause, on the 26th of July, 1798, the cliffs of
France, fifty miles off, were seen as distinctly from
Hastings as if they had been close at hand; and even
Dieppe was said to have been visible in the afternoon.

The stratum of air in the horizon is so much thicker
and more dense than the stratum in the vertical, that
the sun's light is diminished 1300 times in passing
through it, which enables us to look at him when setting
without being dazzled. The loss of light and conse-
quently of heat by the absorbing power of the atmos-
phere, increases with the obliquity of incidence. Of
ten thousand rays falling on its surface, 8123 arrive at a

given point of the earth if they fall perpendicularly;
7024 arrive, if the angle of direction be fifty degrees;
2831, if it be seven degrees; and only five rays will
arrive through a horizontal stratum.   Since so great a
quantity of light is lost in passing through the atmos-
phere, many celestial objects may be altogether invisible
from the plain, which may be seen from elevated situ-
ations.   Diminished splendor, and the false estimate
we make of distance from the number of intervening
objects, lead us to suppose the sun and moon to be
much larger when in the horizon than at any other al-
titude, though their apparent diameters are then some-
what less.   Instead of the sudden transitions of light
and darkness, the reflective power of the air adorns na-
ture with the rosy and golden hues of the Aurora and
twilight.   Even when the sun is eighteen degrees be-
low the horizon, a sufficient portion of light remains to
show, that at the height of thirty miles it is still dense
enough to reflect light.   The atmosphere scatters the
sun's rays, and gives all the beautiful tints and cheerful-
ness of day.   It transmits the blue light in greatest
abundance; the higher we ascend, the sky assumes a
deeper hue; but in the expanse of space, the sun and
stars must appear like brilliant specks in profound
blackness.

SECTION XIX.

Constitution of Light according to Sir Isaac Newton—Absorption of Light
—Colors of Bodies—Constitution of Light according to Sir David Brew-
ster—New Colors in the Solar Spectrum—Fraunhofer's Dark Lines—
Dispersion of Light—The Achromatic Telescope—Homogeneous Light—
Accidental and Complementary Colors—M. Plateau's Experiments and
Theory of Accidental Colors.

IT is impossible thus to trace the path of a sunbeam
through our atmosphere without feeling a desire to
know its nature, by what power it traverses the immen-
sity of space, and the various modifications it undergoes
at the surfaces and in the interior of terrestrial sub-
stances.

Sir Isaac Newton proved the compound nature of
white light as emitted from the sun, by passing a sun-
beam through a glass prism (N. 190), which separating

the rays by refraction, formed a spectrum or oblong
image of the sun, consisting of seven colors, red, orange,
yellow, green, blue, indigo, and violet; of which the
red is the least refrangible and the violet the most. But
when he reunited these seven rays by means of a lens,
the compound beam became pure white as before. He
insulated each colored ray; and finding that it was no
longer capable of decomposition by refraction, concluded
that white light consists of seven kinds of homogeneous
light, and that to the same color the same refrangibility
ever belongs, and to the same refrangibility the same
color. Since the discovery of absorbent media, how-
ever, it appears that this is not the constitution of the
solar spectrum.

We know of no substance that is either perfectly
opaque or perfectly transparent. Even gold may be
beaten so thin as to be pervious to light. On the con-
trary, the clearest crystal, the purest air or water, stops
or absorbs its rays when transmitted, and gradually ex-
tinguishes them as they penetrate to greater depths.
On this account objects cannot be seen at the bottom of
very deep water, and many more stars are visible to the
naked eye from the tops of mountains than from the
valleys. The quantity of light that is incident on any
transparent substance is always greater than the sum of
the reflected and refracted rays. A small quantity is
irregularly reflected in all directions by the imperfec-
tions of the polish by which we are enabled to see the
surface; but a much greater portion is absorbed by the
body. Bodies that reflect all the rays appear white,
those that absorb them all seem black; but most sub-
stances, after decomposing the white light which falls
upon them, reflect some colors and absorb the rest. A
violet reflects the violet rays alone, and absorbs the
others. Scarlet cloth absorbs almost all the colors ex-
cept red. Yellow cloth reflects the yellow rays most
abundantly, and blue cloth those that are blue. Con-
sequently color is not a property of matter, but arises
from the action of matter upon light. Thus a white
riband reflects all the rays, but when dyed red the par-
ticles of the silk acquire the property of reflecting the
red rays most abundantly and of absorbing the others.

crystalized minerals, animal and vegetable substances, gums, resins, jellies, and all solid bodies having unequal tensions, whether from unequal temperature or pressure, possess the property of doubling the image or appearance of an object seen through them in certain directions.   Because a ray of natural light falling upon them is refracted into two pencils, which move with different velocities, and are more or less separated, according to the nature of the body and the direction of the incident ray.   Whenever a ray of natural light is thus divided into two pencils in its passage through a substance, both of the transmitted rays are polarized.   Iceland spar, a carbonate of lime, which by its natural cleavage may be split into the form of a rhombohedron, possesses the property of double refraction in an eminent degree, as may be seen by pasting a piece of paper with a large pin-hole in it, on the side of the spar farthest from the eye.   The hole will appear double when held to the light (N. 200).   One of these pencils is refracted according to the same law as in glass or water, never quitting the plane perpendicular to the refracting surface, and is therefore called the ordinary ray.   But the other does quit the plane, being refracted according to a different and much more complicated law, and on that account is called the extraordinary ray.   For the same reason one image is called the ordinary, and the other the extraordinary image.   When the spar is turned round in the same plane, the extraordinary image of the hole revolves about the ordinary image which remains fixed, both being equally bright.   But if the spar be kept in one position and viewed through a plate of tourmaline, it will be found that as the tourmaline revolves, the images vary in their relative brightness—one increases in intensity till it arrives at a maximum, at the same time that the other diminishes till it vanishes, and so on alternately at each quarter revolution, proving both rays to be polarized.   For in one position the tourmaline transmits the ordinary ray, and reflects the extraordinary; and after revolving 90°, the extraordinary ray is transmitted, and the ordinary ray is reflected.   Thus another property of polarized light is, that it cannot be divided into two equal pencils by double refraction, in

rariety of colored media, Sir David Brewster, so justly
celebrated for his optical discoveries, has proved that
the solar spectrum consists of three primary colors, red,
yellow, and blue, each of which exists throughout its
whole extent, but with different degrees of intensity in
different parts ; and that the superposition of these three
produces all the seven hues according as each primary
color is an excess or defect. Since a certain portion of
red, yellow, and blue rays constitute white light, the
color of any point of the spectrum may be considered
as consisting of the predominating color at that point
mixed with white light. Consequently, by absorbing
the excess of any color at any point of the spectrum
above what is necessary to form white light, such white
light will appear at that point as never mortal eye
looked upon before this experiment, since it possesses
the remarkable property of remaining the same after
any number of refractions, and of being capable of de-
composition by absorption alone.

In addition to the seven colors of the Newtonian spec-
trum, Sir John Herschel has discovered a set of very
dark red rays beyond the red extremity of the spec-
trum, which can only be seen when the eye is defended
from the glare of the other colors by a dark blue cobalt
glass. He has also found that beyond the extreme
violet there are visible rays of a lavender gray color,
which may be seen by throwing the spectrum on a
sheet of paper moistened by the carbonate of soda.
The illuminating power of the different rays of the spec-
trum varies with the color. The most intense light is
in the mean yellow ray.

When the prism is very perfect and the sunbeam
small, so that the spectrum may be received on a sheet
of white paper in its utmost state of purity, it presents
the appearance of a riband shaded with all the prismatic
colors, having its breadth irregularly striped or subdi-
vided by an indefinite number of dark, and sometimes
black, lines. The greater number of these rayless lines
are so extremely narrow that it is impossible to see
them in ordinary circumstances. The best method is
to receive the spectrum on the object glass of a tele-
scope, so as to magnify them sufficiently to render them

visible. This experiment may also be made, but in an imperfect manner, by viewing a narrow slit between two nearly closed window-shutters through a very excellent glass prism held close to the eye, with its refracting angle parallel to the line of light. The rayless lines in the red portion of the spectrum become most visible as the sun approaches the horizon, while those in the blue extremity are most obvious in the middle of the day. When the spectrum is formed by the sun's rays, either direct or indirect—as from the sky, clouds, rainbow, moon, or planets—the black bands are always found to be in the same parts of the spectrum, and under all circumstances to maintain the same relative positions, breadths, and intensities. Similar dark lines are also seen in the light of the stars, in the electric light, and in the flame of combustible substances, though differently arranged, each star and each flame having a system of dark lines peculiar to itself, which remains the same under every circumstance. Dr. Wollaston and M. Fraunhofer of Munich discovered these lines deficient of rays independently of each other. M. Fraunhofer found that their number extends to nearly six hundred. There are bright lines in the solar spectrum which also maintain a fixed position. Among the dark lines, M. Fraunhofer selected seven of the most remarkable, and determined their distances so accurately, that they now form standard and invariable points of reference for measuring the refractive powers of different media on the rays of light, which renders this department of optics as exact as any of the physical sciences. These lines are designated by the letters of the alphabet, beginning with B, which is in the red near the end of the spectrum; C is farther advanced in the red; D is in the orange; E, in the green; F, in the blue; G, in the indigo; and H, in the violet. By means of these fixed points, M. Fraunhofer has ascertained from prismatic observation the refrangibility of seven of the principal rays in each of ten different substances solid and liquid. The refraction increased in all from the red to the violet end of the spectrum; but so irregularly for each ray and in each medium, that no law could be discovered. The rays that are wanting in the solar spectrum which occasion the dark lines,

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of deep regret to all who take an interest in the higher
paths of scientific research.

When a beam of common light is partly reflected at,
and partly transmitted through, a transparent surface,
the reflected and refracted pencils contain equal quanti-
ties of polarized light, and their planes of polarization
are at right angles to one another: hence a pile of panes
of glass will give a polarized beam by refraction. For if
a ray of common light pass through them, part of it
will be polarized by the first plate, the second plate will
polarize a part of what passes through it, and the rest
will do the same in succession, till the whole beam is
polarized, except what is lost by reflection at the dif-
ferent surfaces, or by absorption. This beam is polar-
ized in a plane at right angles to the plane of reflection,
that is, at right angles to the plane passing through the
incident and reflected ray (N. 203).

By far the most convenient way of polarizing light is
by reflection. A plane of plate-glass laid upon a piece
of black cloth, on a table at an open window, will appear
of a uniform brightness from the reflection of the sky
or clouds. But if it be viewed through a plate of tour-
maline, having its axis vertical, instead of being illumi-
nated as before, it will be obscured by a large cloudy
spot, having its center quite dark, which will readily be
found by elevating or depressing the eye, and will only
be visible when the angle of incidence is 57°, that is,
when the line from the eye to the center of the black
spot makes an angle of 33° with the surface of the re-
flector (N. 204). When the tourmaline is turned round
in its own plane, the dark cloud will diminish, and en-
tirely vanish when the axis of the tourmaline is horizon-
tal, and then every part of the surface of the glass will
be equally illuminated. As the tourmaline revolves, the
cloudy spot will appear and vanish alternately at every
quarter revolution. Thus, when a ray of light is inci-
dent on a pane of plate-glass at an angle of 57°, the re-
flected ray is rendered incapable of penetrating a plate
of tourmaline, whose axis is in the plane of incidence.
Consequently it has acquired the same character as if
it had been polarized by transmission through a plate
of tourmaline, with its axis at right angles to the plane

flint glass is much greater than the space occupied by that produced by the crown glass; and as the quantity of dispersion depends upon the refracting angle of the prism, the angles of the two prisms may be made such, that when the prisms are placed close together with their edges turned opposite ways, they will exactly oppose each other's action, and will refract the colored rays equally but in contrary directions, so that an exact compensation will be effected, and the light will be refracted without color (N. 191).   The achromatic telescope is constructed on this principle.   It consists of a tube with an object glass or lens at one end to bring the rays to a focus and form an image of the distant object, and a magnifying glass at the other end to view the image thus formed.   Now it is found that the object-glass, instead of making the rays converge to one point, disperses them, and gives a confused and colored image: but by constructing it of two lenses in contact, one of flint and the other of crown glass of certain forms and proportions, the dispersion is counteracted, and a perfectly well defined and colorless image of the object is formed (N. 192).   It was thought to be impossible to produce refraction without color, till Mr. Hall, a gentleman of Worcestershire, constructed a telescope on this principle in the year 1733; and twenty-five years afterward, the achromatic telescope was brought to perfection by Mr. Dollond, a celebrated optician in London.

A perfectly homogeneous color is very rarely to be found, but the tints of all substances are most brilliant when viewed in light of their own color.   The red of a wafer is much more vivid in red than in white light; whereas if placed in homogeneous yellow light, it can no longer appear red, because there is not a ray of red in the yellow light.   Were it not that the wafer, like all other bodies, whether colored or not, reflects white light at its outer surface, it would appear absolutely black when placed in yellow light.

After looking steadily for a short time at a colored object, such as a red wafer, on turning the eyes to a white substance, a green image of the wafer appears, which is called the accidental color of red.   All tints have their accidental colors :—thus the accidental color

greater or less than a polarizing angle, a part only of
the reflected ray will be polarized, but a part of what is
transmitted will be polarized by reflection at the sur-
face of the second plate, part at the third, and so on till
the whole is polarized.   This is the best apparatus ; but
one plate of glass having its inferior surface blackened,
or even a polished table, will answer the purpose.

Section XXII.

Phenomena exhibited by the passage of Polarized Light through Mica and
Sulphate of Lime—The Colored Images produced by Polarized Light
passing through Crystals having one and two Optic Axes—Circular
Polarization—Elliptical Polarization—Discoveries of MM. Biot, Fresnel,
and Professor Airy—Colored Images produced by the Interference of
Polarized Rays.

Such is the nature of polarized light and of the laws
it follows.   But it is hardly possible to convey an idea of
the splendor of the phenomena it exhibits under circum-
stances which an attempt will now be made to describe.

If light polarized by reflection from a pane of glass be
viewed through a plate of tourmaline, with its longitudi-
nal section vertical, an obscure cloud, with its center
totally dark, will be seen on the glass.   Now let a plate
of mica, uniformly about the thirtieth of an inch in thick-
ness, be interposed between the tourmaline and the
glass ; the dark spot will instantly vanish, and instead of
it, a succession of the most gorgeous colors will appear,
varying with every inclination of the mica, from the
richest reds, to the most vivid greens, blues, and purples
(N. 206).   That they may be seen in perfection, the
mica must revolve at right angles to its own plane.
When the mica is turned round in a plane perpendicu-
lar to the polarized ray, it will be found that there are
two lines in it where the colors entirely vanish.   These
are the optic axes of the mica, which is a doubly refract-
ing substance, with two optic axes, along which light is
refracted in one pencil.

No colors are visible in the mica, whatever its position
may be with regard to the polarized light, without the
aid of the tourmaline, which separates the transmitted
ray into two pencils of colored light complementary to

one another, that is, which taken together would make
white light.   One of these it absorbs, and transmits the
other ; it is therefore called the analyzing plate.   The
truth of this will appear more readily, if a film of sul-
phate of lime between the twentieth and sixtieth of an
inch thick be used instead of the mica.   When the film
is of uniform thickness, only one color will be seen when
it is placed between the analyzing plate and the reflect-
ing glass ; as, for example, red.   But when the tourma-
line revolves, the red will vanish by degrees till the film
is colorless ; then it will assume a green hue, which
will increase and arrive at its maximum when the tour-
maline has turned through ninety degrees ; after that
the green will vanish and the red will reappear, alter-
nating at each quadrant.   Thus the tourmaline separ-
ates the light which has passed through the film into a
red and a green pencil ; in one position it absorbs the
green and lets the red pass, and in another it absorbs
the red and transmits the green.   This is proved by
analyzing the ray with Iceland spar instead of tourmaline;
for since the spar does not absorb the light, two images
of the sulphate of lime will be seen, one red and the
other green, and these exchange colors every quarter
revolution of the spar, the red becoming green, and the
green red ; and where the images overlap, the color is
white, proving the red and green to be complementary
to each other.   The tint depends on the thickness of
the film.   Films of sulphate of lime, the 0·00124 and
0·01818 of an inch respectively, give white light in what-
ever position they may be held, provided they be per-
pendicular to the polarized ray ; but films of interme-
diate thickness will give all colors.   Consequently, a
wedge of sulphate of lime, varying in thickness between
the 0·00124 and the 0·01818 of an inch, will appear to
be striped with all colors when polarized light is trans-
mitted through it.   A change in the inclination of the
film, whether of mica or sulphate of lime, is evidently
equivalent to a variation in thickness.

When a plate of mica, held as close to the eyes as
possible at such an inclination as to transmit the polar-
ized ray along one of its optic axes, is viewed through the
tourmaline with its axis vertical, a most splendid appear-

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ance is presented. The cloudy spot in the direction of
the optic axis is seen surrounded by a set of vividly
colored rings of an oval form, divided into two unequal
parts by a black curved band passing through the cloudy
spot about which the rings are formed. The other optic
axis of the mica exhibits a similar image (N. 207).

When the two optic axes of a crystal make a small
angle with one another, as in nitre, the two sets of rings
touch externally; and if the plate of nitre be turned round
in its own plane, the black transverse bands undergo
a variety of changes, till at last the whole richly colored
image assumes the form of the figure 8, traversed by a
black cross (N. 208). Substances with one optic axis
have but one set of colored circular rings, with a broad
black cross passing through its center, dividing the rings
into four equal parts. When the analyzing plate re-
volves, this figure recurs at every quarter revolution;
but in the intermediate positions it assumes the com-
plementary colors, the black cross becoming white.

It is in vain to attempt to describe the beautiful phe-
nomena exhibited by innumerable bodies, which undergo
periodic changes in form and color when the analyzing
plate revolves, but not one of them shows a trace of
color without the aid of tourmaline or something equiv-
alent to analyze the light, and as it were to call these
beautiful phantoms into existence. Tourmaline has the
disadvantage of being itself a colored substance; but
that inconvenience may be obviated by employing a re-
flecting surface as an analyzing plate. When polarized
light is reflected by a plate of glass at the polarizing
angle, it will be separated into two colored pencils; and
when the analyzing plate is turned round in its own
plane, it will alternately reflect each ray at every quar-
ter revolution, so that all the phenomena that have been
described will be seen by reflection on its surface.

Colored rings are produced by analyzing polarized
light transmitted through glass melted and suddenly or
unequally cooled; also through thin plates of glass
bent with the hand, jelly indurated or compressed, &c.
&c. In short, all the phenomena of colored rings may
be produced, either permanently or transiently, in a
variety of substances, by heat and cold, rapid cooling,

compression, dilatation, and induration; and so little apparatus is necessary for performing the experiments, that, as Sir John Herschel says, a piece of window-glass or a polished table to polarize the light, a sheet of clear ice to produce the rings, and a broken fragment of plate-glass placed near the eye to analyze the light, are alone requisite to produce one of the most splendid of optical exhibitions.

It has been observed, that when a ray of light, polarized by reflection from any surface not metallic, is analyzed by a doubly refracting substance, it exhibits properties which are symmetrical both to the right and left of the plane of reflection, and the ray is then said to be polarized according to that plane. This symmetry is not destroyed when the ray, before being analyzed, traverses the optic axis of a crystal having but one optic axis, as evidently appears from the circular forms of the colored rings already described. Regularly crystalized quartz, however, forms an exception. In it, even though the rays should pass through the optic axis itself, where there is no double refraction, the primitive symmetry of the ray is destroyed, and the plane of primitive polarization deviates either to the right or left of the observer, by an angle proportional to the thickness of the plate of quartz. This angular motion, or true rotation of the plane of polarization, which is called circular polarization, is clearly proved by the phenomena. The colored rings produced by all crystals having but one optic axis are circular, and traversed by a black cross concentric with the rings; so that the light entirely vanishes throughout the space inclosed by the interior ring, because there is neither double refraction nor polarization along the optic axis. But in the system of rings produced by a plate of quartz, whose surfaces are perpendicular to the axis of the crystal, the part within the interior ring, instead of being void of light, is occupied by a uniform tint of red, green, or blue, according to the thickness of the plate (N. 209). Suppose the plate of quartz to be $\frac{1}{25}$ of an inch thick, which will give the red tint to the space within the interior ring; when the analyzing plate is turned in its own plane through an angle of $17\frac{1}{2}°$, the

red hue vanishes. If a plate of rock crystal $\frac{2}{25}$ of an inch thick be used, the analyzing plate must revolve through 35° before the red tint vanishes, and so on; every additional 25th of an inch in thickness requiring an additional rotation of $17\frac{1}{2}°$; whence it is manifest that the plane of polarization revolves in the direction of a spiral within the rock crystal. It is remarkable that in some crystals of quartz, the plane of polarization revolves from right to left, and in others from left to right, although the crystals themselves differ apparently only by a very slight, almost imperceptible variety in form. In these phenomena, the rotation to the right is accomplished according to the same laws, and with the same energy, as that to the left. But if two plates of quartz be interposed which possess different affections, the second plate undoes, either wholly or partly, the rotatory motion which the first had produced, according as the plates are of equal or unequal thickness. When the plates are of unequal thickness, the deviation is in the direction of the strongest, and exactly the same with that which a third plate would produce equal in thickness to the difference of the two.

M. Biot has discovered the same properties in a variety of liquids. Oil of turpentine, and an essential oil of laurel, cause the plane of polarization to turn to the left, whereas the syrup of sugar-cane, and a solution of natural camphor by alcohol, turn it to the right. A compensation is effected by the superposition or mixture of two liquids which possess these opposite properties, provided no chemical action takes place. A remarkable difference was also observed by M. Biot between the action of the particles of the same substances when in a liquid or solid state. The syrup of grapes, for example, turns the plane of polarization to the left as long as it remains liquid; but as soon as it acquires the solid form of sugar, it causes the plane of polarization to revolve toward the right, a property which it retains even when again dissolved. Instances occur also in which these circumstances are reversed.

A ray of light passing through a liquid possessing the power of circular polarization is not affected by mixing other fluids with the liquid—such as water, ether, alco-

hol, &c.—which do not possess circular polarization
themselves, the angle of deviation remaining exactly the
same as before the mixture. Whence M. Biot infers
that the action exercised by the liquids in question
does not depend upon their mass, but that it is a mole-
cular action exercised by the ultimate particles of mat-
ter, which depends solely upon the individual constitu-
tion, and is entirely independent of the positions and
mutual distances of the particles with regard to each
other. These important discoveries show, that circular
polarization surpasses the power of chemical analysis in
giving certain and direct evidence of the similarity or
difference existing in the molecular constitution of bodies,
as well as of the permanency of that constitution, or of
the fluctuations to which it may be liable. For example,
no chemical difference has been discovered between
syrup from the sugar-cane and syrup from grapes. Yet
the first causes the plane of polarization to revolve to
the right, and the other to the left; therefore some es-
sential difference must exist in the nature of their ulti-
mate molecules. The same difference is to be traced
between the juices of such plants as give sugar similar
to that from the cane, and those which give sugar like
that obtained from grapes. This eminent philosopher
is now engaged in a series of experiments on the pro-
gressive changes in the sap of vegetables at different
distances from their roots, and on the products that are
formed at the various epochs of vegetation, from their
action on polarized light.

It is a fact established by M. Biot, that in circular
polarization, the laws of rotation followed by the differ-
ent simple rays of light are dissimilar in different sub-
stances. Whence he infers that the deviation of the
simple rays from one another ought not to result from
a special property of the luminous principle only, but
that the proper action of the molecules must also concur
in modifying the deviations of the simple rays differently
in different substances.

One of the many brilliant discoveries of M. Fresne
is the production of circular and elliptical polarization by
the internal reflection of light from plate glass. He has
shown that if light polarized by any of the usual methods

be twice reflected within a glass rhomb (N. 166) of a given form, the vibrations of the ether that are perpendicular to the plane of incidence will be retarded a quarter of a vibration, which causes the vibrating particles to describe circles, and the succession of such vibrating particles throughout the extent of a wave to form altogether a circular helix, or curve like a corkscrew. However, that only happens when the plane of polarization is inclined at an angle of 45° to the plane of incidence. When these two planes form an angle either greater or less, the succession of vibrating particles forms an elliptical helix, which curve may be represented by twisting a thread in a spiral about an oval rod. These curves will turn to the right or left, according to the position of the incident plane.

The motion of the ethereal medium in elliptical and circular polarization may be represented by the analogy of a stretched cord; for if the extremity of such a cord be agitated at equal and regular intervals by a vibratory motion entirely confined to one plane, the cord will be thrown into an undulating curve lying wholly in that plane. If to this motion there be superadded another similar and equal, but perpendicular to the first, the cord will assume the form of an elliptical helix; its extremity will describe an ellipse, and every molecule throughout its length will successively do the same. But if the second system of vibrations commence exactly a quarter of an undulation later than the first, the cord will take the form of a circular helix or cork-screw; the extremity will move uniformly in a circle, and every molecule throughout the cord will do the same in succession. It appears, therefore, that both circular and elliptical polarization may be produced, by the composition of the motions of two rays in which the particles of ether vibrate in planes at right angles to one another.

Professor Airy, in a very profound and able paper published in the Cambridge Transactions, has proved that all the different kinds of polarized light are obtained from rock crystal. When polarized light is transmitted through the axis of a crystal of quartz, in the emergent ray the particles of ether move in a circular helix; and when it is transmitted obliquely so as to form an angle

with the axis of the prism, the particles of ether move
in an elliptical helix, the ellipticity increasing with the
obliquity of the incident ray; so that, when the incident
ray falls perpendicularly to the axis, the particles of
ether move in a straight line. Thus quartz exhibits
every variety of elliptical polarization, even including
the extreme cases where the eccentricity is zero, or
equal to the greater axis of the ellipse (N. 210). In
many crystals the two rays are so little separated, that
it is only from the nature of the transmitted light that
they are known to have the property of double refrac-
tion. M. Fresnel discovered by experiments on the
properties of light passing through the axis of quartz,
that it consists of two superposed rays, moving with
different velocities; and Professor Airy has shown, that
in these two rays, the molecules of ether vibrate in
similar ellipses at right angles to each other, but in dif-
ferent directions; that their ellipticity varies with the
angle which the incident ray makes with the axis; and
that, by the composition of their motions, they produce
all the phenomena of polarized light observed in quartz.

It appears from what has been said, that the mole-
cules of ether always perform their vibrations at right
angles to the direction of the ray, but very differently in
the various kinds of light. In natural light the vibrations
are rectilinear, and in every plane. In ordinary polar-
ized light they are rectilinear, but confined to one plane;
in circular polarization the vibrations are circular; and
in elliptical polarization the molecules vibrate in ellipses.
These vibrations are communicated from molecule to
molecule, in straight lines when they are rectilinear, in
a circular helix when they are circular, and in an oval
or elliptical helix when elliptical.

Some fluids possess the property of circular polar-
ization, as oil of turpentine; and elliptical polarization,
or something similar, seems to be produced by reflection
from metallic surfaces.

The colored images from polarized light arise from
the interference of the rays (N. 211). MM. Fresnel
and Arago found that two rays of polarized light inter-
fere and produce colored fringes if they be polarized in
the same plane, but that they do not interfere when

polarized in different planes. In all intermediate positions, fringes of intermediate brightness are produced. The analogy of a stretched cord will show how this happens. Suppose the cord to be moved backward and forward horizontally at equal intervals; it will be thrown into an undulating curve lying all in one plane. If to this motion there be superadded another similar and equal, commencing exactly half an undulation later than the first, it is evident that the direct motion every molecule will assume, in consequence of the first system of waves, will at every instant be exactly neutralized by the retrograde motion it would take in virtue of the second; and the cord itself will be quiescent in consequence of the interference. But if the second system of waves be in a plane perpendicular to the first, the effect would only be to twist the rope, so that no interference would take place. Rays polarized at right angles to each other may subsequently be brought into the same plane without acquiring the property of producing colored fringes; but if they belong to a pencil the whole of which was originally polarized in the same plane, they will interfere.

The manner in which the colored images are formed may be conceived, by considering that when polarized light passes through the optic axis of a doubly refracting substance,—as mica, for example,—it is divided into two pencils by the analyzing tourmaline; and as one ray is absorbed there can be no interference. But when polarized light passes through the mica in any other direction, it is separated into two white rays, and these are again divided into four pencils by the tourmaline, which absorbs two of them; and the other two, being transmitted in the same plane with different velocities, interfere and produce the colored phenomena. If the analysis be made with Iceland spar, the single ray passing through the optic axis of the mica will be refracted into two rays polarized in different planes, and no interference will happen. But when two rays are transmitted by the mica, they will be separated into four by the spar, two of which will interfere to form one image, and the other two, by their interference, will produce the complementary colors of the other image, when the

spar has revolved through 90°; because, in such posi-
tions of the spar as produce the colored images, only
two rays are visible at a time, the other two being re-
flected.   When the analysis is accomplished by reflec-
tion, if two rays are transmitted by the mica, they are
polarized in planes at right angles to each other.   And
if the plane of reflection of either of these rays be at
right angles to the plane of polarization, only one of
them will be reflected, and therefore no interference
can take place; but in all other positions of the analy-
zing plate both rays will be reflected in the same plane,
and consequently will produce colored rings by their
interference.

It is evident that a great deal of the light we see must
be polarized, since most bodies which have the power
of reflecting or refracting light also have the power of
polarizing it.   The blue light of the sky is completely
polarized at an angle of 74° from the sun in a plane
passing through his center.

A constellation of talent almost unrivaled at any
period in the history of science, has contributed to the
theory of polarization, though the original discovery of
that property of light was accidental, and arose from an
occurrence which like thousands of others would have
passed unnoticed, had it not happened to one of those
rare minds capable of drawing the most important in-
ferences from circumstances apparently trifling.   In
1808, while M. Malus was accidently viewing with a
doubly-refracting prism a brilliant sunset reflected from
the windows of the Luxembourg palace in Paris, on
turning the prism slowly round, he was surprised to
see a very great difference in the intensity of the two
images, the most refracted alternately changing from
brightness to obscurity at each quadrant of revolution.
A phenomenon so unlooked for induced him to investi-
gate its cause, whence sprung one of the most elegant
and refined branches of physical optics.

X

Section XXIII.

Objections to the Undulatory Theory, from a Difference in the Action of Sound and Light under the same circumstances, removed—The Dispersion of Light according to the Undulatory Theory.

The numerous phenomena of periodical colors arising from the interference of light, which do not admit of satisfactory explanation on any other principle than the undulatory theory, are the strongest arguments in favor of that hypothesis; and even cases which at one time seemed unfavorable to that doctrine have proved upon investigation to proceed from it alone. Such is the erroneous objection which has been made, in consequence of a difference in the mode of action of light and sound, under the same circumstances, in one particular instance. When a ray of light from a luminous point, and a diverging sound, are both transmitted through a very small hole into a dark room, the light goes straight forward and illuminates a small spot on the opposite wall, leaving the rest in darkness; whereas the sound on entering diverges in all directions, and is heard in every part of the room. These phenomena, however, instead of being at variance with the undulatory theory, are direct consequences of it, arising from the very great difference between the magnitude of the undulations of sound and those of light. The undulations of light are incomparably less than the minute aperture, while those of sound are much greater. Therefore when light diverging from a luminous point enters the hole, the rays round its edges are oblique, and consequently of different lengths, while those in the center are direct, and nearly or altogether of the same lengths. So that the small undulations between the center and the edges are in different phases, that is, in different states of undulation. Therefore the greater number of them interfere, and by destroying one another produce darkness all around the edges of the aperture; whereas the central rays having the same phases, combine, and produce a spot of bright light on a wall or screen directly opposite the hole. The waves of air producing sound, on the

contrary, being very large compared with the hole, do not sensibly diverge in passing through it. and are therefore all so nearly of the same length, and consequently in the same phase, or state of undulation, that none of them interfere sufficiently to destroy one another. Hence all the particles of air in the room are set into a state of vibration, so that the intensity of the sound is very nearly everywhere the same. Strong as the preceding cases may be, the following experiment made by M. Arago about twenty years ago seems to be decisive in favor of the undulatory doctrine. Suppose a plano-convex lens of very great radius to be placed upon a plate of very highly polished metal. When a ray of polarized light falls upon this apparatus at a very great angle of incidence, Newton's rings are seen at the point of contact. But as the polarizing angle of glass differs from that of metal, when the light falls on the lens at the polarizing angle of glass, the black spot and the system of rings vanish. For although light in abundance continues to be reflected from the surface of the metal, not a ray is reflected from the surface of the glass that is in contact with it, consequently no interference can take place ; which proves, beyond a doubt, that Newton's rings result from the interference of the light reflected from both the surfaces apparently in contact (N. 194).

Notwithstanding the successful adaptation of the undulatory system to phenomena, the dispersion of light for a long time offered a formidable objection to that theory, which has only been removed during the present year by Professor Powell of Oxford.

A sunbeam falling on a prism, instead of being refracted to a single point of white light, is separated into its component colors, which are dispersed or scattered unequally over a considerable space, of which the portion occupied by the red rays is the least, and that over which the violet rays are dispersed is the greatest. Thus the rays of the colored spectrum whose waves are of different lengths, have different degrees of refrangibility, and consequently move with different velocities, either in the medium which conveys the light from the sun, or in the refracting medium, or in both ; whereas rays of all colors

come from the sun to the earth with the same velocity. If, indeed, the velocities of the various rays were different in space, the aberration of the fixed stars, which is inversely as the velocity, would be different for different colors, and every star would appear as a spectrum whose length would be parallel to the direction of the earth's motion, which is not found to agree with observation. Besides, there is no such difference in the velocities of the long and short waves of air in the analogous case of sound, since notes of the lowest and highest pitch are heard in the order in which they are struck. In fact, when the sunbeam passes from air into the prism its velocity is diminished; and as its refraction and consequently its dispersion depend solely upon the diminished velocity of the transmission of its waves, they ought to be the same for waves of all lengths, unless a connection exists between the length of a wave, and the velocity with which it is propagated. Now this connection between the length of a wave of any color and its velocity or refrangibility in a given medium, has been deduced by Professor Powell from M. Cauchy's investigations of the properties of light on a peculiar modification of the undulatory hypothesis. Hence the refrangibility of the various colored rays computed from this relation for any given medium, when compared with their refrangibility in the same medium determined by actual observation, will show whether the dispersion of light comes under the laws of that theory. But in order to accomplish this, it is clear that the length of the waves should be found independently of refraction, and a very beautiful discovery of M. Fraunhofer furnishes the means of doing so.

That philosopher obtained a perfectly pure and complete colored spectrum with all its dark and bright lines by the interference of light alone, from a sunbeam passing through a series of fine parallel wires covering the object glass of a telescope. In this spectrum, formed independently of prismatic refraction, the positions of the colored rays depend only on the lengths of their waves, and M. Fraunhofer found that the intervals between them are precisely proportional to the differences of these lengths. He measured the lengths of the waves

of the different colors at seven fixed points, determined by seven of the principal dark and bright lines. Professor Powell, availing himself of these measures, has made the requisite computations, and has found that the coincidence of theory with observation is perfect for ten substances whose refrangibility had been previously determined by the direct measurements of M. Fraunhofer, and for ten others whose refrangibility has more recently been ascertained by M. Rudberg. Thus, in the case of seven rays in each of twenty different substances solid and fluid, the dispersion of light takes place according to the laws of the undulatory theory; and as there can hardly be a doubt that dispersion in all other bodies will be found to follow the same law, the undulatory theory of light may now be regarded as completely established. It is however an express condition of the connection between the velocity of light and the length of its undulations, that the intervals between the vibrating molecules of the ethereal fluid should bear a sensible relation to the length of an undulation. The coincidence of the computed with the observed refractions shows that this condition is fulfilled within the refracting media; but the aberration of the fixed stars leads to the inference that it does not hold in the ethereal regions, where the velocities of the rays of all colors are the same.

Section XXIV.

Chemical or Photographic Rays of the Solar Spectrum—Messrs. Scheele, Ritter, and Wollaston's Discoveries—Mr. Wedgewood and Sir Humphry Davy's Photographic Pictures—The Calotype—The Daguerreotype—The Chromatype—The Cyanotype—Sir John Herschel's Discoveries in the Photographic or Chemical Spectrum—Mons. E. Becquerel's Discovery of Inactive Lines in the Chemical Spectrum.

THE solar spectrum has assumed a totally new character from recent analysis, especially the chemical portion, which exercises an energetic action on matter, producing the most wonderful and mysterious changes on the organized and unorganized creation.

All bodies are probably affected by light, but it acts with greatest energy on such as are of weak chemical affinity, imparting properties to them which they did

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not possess before. Metallic salts, especially those of silver, whose molecules are held together by an unstable equilibrium, are of all bodies the most susceptible of its influence; the effects however vary with the substances employed and with the different rays of the solar spectrum, the chemical properties of which are by no means alike. As early as 1772 M. Scheele showed that the pure white color of chloride of silver was rapidly darkened by the blue rays of the solar spectrum, while the red rays had no effect upon it; and in 1801 M. Ritter discovered that invisible rays beyond the violet extremity have the property of blackening argentine salts, that this property diminishes toward the less refrangible part of the spectrum, and that the red rays have an opposite quality, that of restoring the blackened salt of silver to its original purity, from which he inferred that the most refrangible extremity of the spectrum has an oxygenizing power, and the other that of deoxygenating. Dr. Wollaston found that gum guaiacum acquires a green color in the violet and blue rays, and resumes its original tint in the red. No attempt had been made to trace natural objects by means of light reflected from them till Mr. Wedgewood, together with Sir Humphry Davy, took up the subject: they produced profiles and tracings of objects on surfaces prepared with nitrate and chloride of silver, but they did not succeed in rendering their pictures permanent. This difficulty was overcome in 1814 by M. Niepcé, who produced a permanent picture of surrounding objects, by placing in the focus of a camera obscura, a metallic plate covered with a film of asphalt dissolved in oil of lavender.

Mr. Fox Talbot, without any knowledge of M. Niepcé's experiments, had been engaged in the same pursuit, and must be regarded as an independent inventor of photography, one of the most beautiful arts of modern times: he was the first who succeeded in using paper chemically prepared for receiving impressions from natural objects; and he also discovered a method of fixing permanently the impressions—that is, of rendering the paper insensible to any further action of light. In the calotype, one of Mr. Talbot's most recent applications of the art, this photographic surface is prepared by wash-

ing smooth writing-paper, first with a solution of nitrate of silver, then with bromide of potassium, and again with nitrate of silver, drying it at a fire after each washing; the paper is thus rendered so sensitive to light that even the passage of a thin cloud is perceptible on it, consequently it must be prepared by candle-light. Portraits, buildings, insects, leaves of plants, in short every object is accurately delineated in a few seconds, and in the focus of a camera-obscura the most minute objects are so exactly depicted that the microscope reveals new beauties.

Since the effect of the chemical agency of light is to destroy the affinity between the salt and the silver, Mr. Talbot found that in order to render these impressions permanent on paper, it was only necessary to wash it with salt and water, or with a solution of iodide of potassium. For these liquids the liquid hyposulphites have been advantageously substituted, which are the most efficacious in dissolving and removing the unchanged salt, leaving the reduced silver on the paper. The calotype picture is negative, that is, the lights and shadows are the reverse of what they are in nature, and the right-hand side in nature is the left in the picture; but if it be placed with its face pressed against photographic paper, between a board and a plate of glass, and exposed to the sun a short time, a positive and direct picture as it is in nature is formed; engravings may be exactly copied by this simple process, and a direct picture may be produced at once by using photographic paper already made brown by exposure to light.

While Mr. Fox Talbot was engaged in these very elegant discoveries in England, M. Daguerre had brought to perfection and made public that admirable process by which he has compelled Nature permanently to engrave her own works; and thus the talents of France and England have been combined in bringing to perfection this useful art. Copper, plated with silver, is successfully employed by M. Daguerre for copying nature by the agency of light. The surface of the plate is converted into an iodide of silver, by placing it horizontally with its face downward in a covered box, in the bottom of which there is a small quantity of iodine

which evaporates spontaneously. In three or four
minutes the surface acquires a yellow tint, and then,
screening it carefully from light, it must be placed in
the focus of a camera obscura, where an invisible image
of external objects will be impressed on it in a few
minutes. When taken out the plate must be exposed
in another box to the action of mercurial vapor, which
attaches itself to those parts of the plate which had
been exposed to light, but does not adhere to such parts
as had been in shadow; and as the quantity of mercury
over the other parts is in exact proportion to the de-
gree of illumination, the shading of the picture is per-
fect. The image is fixed, first by removing the iodine
from the plate, by plunging it into hyposulphite of soda,
and then washing it in distilled water; by this process
the yellow color is destroyed, and in order to render
the mercury permanent, the plate must be exposed a
few minutes to nitric vapor, then placed in nitric acid
containing copper or silver in solution at a temperature
of $61\frac{1}{4}°$ of Fahrenheit for a short time, and lastly
polished with chalk. This final part of the process is
due to Dr. Berre, of Vienna.

Nothing can be more beautiful than the shading of
these chiar-oscuro pictures when objects are at rest,
but the least motion destroys the effect; the method
therefore is more applicable to buildings than landscape.
Color alone is wanting; but the researches of Sir John
Herschel give reason to believe that even this will ulti-
mately be attained.

The most perfect impressions of seaweeds, leaves of
plants, feathers, &c., may be formed by bringing the
object into close contact with a sheet of photographic
paper, between a board and plate of glass; then ex-
posing the whole to the sun for a short time, and after-
ward fixing it by the process described. The colors of
the pictures vary with the preparation of the paper, by
which almost any tint may be produced.

In the chromatype, a peculiar photograph discovered
by Mr. Hunt, chromate of copper is used, on which a
dark brown negative image is first formed, but by the
continued action of light it is changed to a positive
yellow picture on a white ground; the farther effect

of light is checked by washing the picture in pure water.

In cyanotypes, a class of photographs discovered by Sir John Herschel, in which cyanogen in its combinations with iron forms the ground, the pictures are Prussian blue and white. In the chrysotype of the same eminent philosopher, the image is first received on paper prepared with the ammonia-citrate of iron, and afterward washed with a neutral solution of gold. It is fixed by water acidulated with sulphuric acid, and lastly by hydriodate of potash, from which a white and purple photograph results. It is vain to attempt to describe the various beautiful effects which Sir John Herschel obtained from chemical compounds, and from the juices of plants: the juice of the red poppy gives a positive bluish purple image, that of the ten-week stock a fine rose color on a pale straw-colored ground.

Pictures may be made by exposure to sunshine, on all compound substances having a weak chemical affinity, but the image is often invisible, as in the Daguerreotype, till brought out by washing in some chemical preparation. Water is frequently sufficient; indeed Sir John Herschel brought out dormant photographs by breathing on them, and some substances are insensible to the action of light till moistened, as for example gum guaiacum. Argentine papers, however, are little subject to the influence of moisture. The power of the solar rays is augmented in certain cases by placing a plate of glass in close contact over the sensitive surface.

Chemical action always accompanies the sun's light, but the analysis of the solar spectrum has partly disclosed the wonderful nature of the emanation. In the research, properties most important and unexpected have been discovered by Sir John Herschel, who imprints the stamp of genius on all he touches—his eloquent papers can alone convey an adequate idea of their value in opening a field of inquiry vast and untrodden. The following brief and imperfect account of his experiments is all that can be attempted here :—

A certain degree of chemical energy is distributed through every part of the solar spectrum, and also to a considerable extent through the dark spaces at each ex-

tremity. This distribution does not depend on the re-
frangibility of the rays alone, but also on the nature of
the rays themselves, and on the physical properties of
the analyzing medium on which the rays are received,
whose changes indicate and measure their action. The
length of the photographic image of the *same* solar spec-
trum varies with the physical qualities of the surface on
which it is impressed. When the solar spectrum is
received on paper prepared with bromide of silver, the
chemical spectrum, as indicated merely by the length of
the darkened part, includes within its limits the whole
luminous spectrum, extending in one direction far be-
yond the extreme violet and lavender rays, and in the
other down to the extremest red : with tartrate of sil-
ver the darkening occupies not only all the space under
the most refrangible rays, but reaches much beyond the
extreme red. On paper prepared with formobenzoate
of silver the chemical spectrum is cut off at the orange
rays, with phosphate of silver in the yellow, and with
chloride of gold it terminates with the green, with car-
bonate of mercury it ends in the blue, and on paper
prepared with the percyanide of gold, ammonia, and
nitrate of silver, the darkening lies entirely beyond the
visible spectrum at its most refrangible extremity, and
is only half its length, whereas in some cases chemical
action occupies a space more than twice the length of
the luminous image.

The point of maximum energy of chemical action
varies as much for different preparations as the scale of
action.   In the greater number of cases the point of
deepest blackening lies about the lower edge of the in-
digo rays, though in no two cases is it exactly the same,
and in many substances it is widely different. On paper
prepared with the juice of the ten-week stock (Mathiola
annua), there are two maxima, one in the mean yellow
and a weaker in the violet ; and on a preparation of tar-
trate of silver, Sir John Herschel found three, one in
the least refrangible blue, one in the indigo, and a third
beyond the visible violet.   The decrease in photographic
energy is seldom perfectly alike on both sides of the
maximum. Thus at the most refrangible end of the
solar spectrum the greatest chemical power is exerted

in most instances where there is least light and heat,
and even in the space where both sensibly cease.

Not only the intensity but the kind of action is differ-
ent in the different points of the solar spectrum, as
evidently appears from the various colors that are fre-
quently impressed on the same analyzing surface, each
ray having a tendency to impart its own color. Sir John
Herschel obtained a colored image of the solar spectrum
on paper prepared according to Mr. Talbot's principle,
from a sunbeam refracted by a glass prism and then
highly condensed by a lens. The photographic image
was rapidly formed and very intense, and when with-
drawn from the spectrum and viewed in common day-
light it was found to be colored with sombre but une-
quivocal tints imitating the prismatic colors, which varied
gradually from red through green and blue to a purplish
black. After washing the surface in water, the tints
became more decided by being kept a few days in the
dark—a phenomenon, Sir John observes, of constant
occurrence, whatever be the preparation of the paper,
provided colors are produced at all. He also obtained a
colored image on nitrate of silver, the part under the
blue rays becoming a blue brown, while that under the
violet had a pinkish shade, and sometimes green ap-
peared at the point corresponding to the least refrangible
blue. Mr. Hunt found on a paper prepared with fluoride
of silver that a yellow line was impressed on the space
occupied by the yellow rays, a green band on the space
under the green rays, an intense blue throughout the
space on which the blue and indigo rays fell, and under
the violet rays a ruddy brown appeared ; these colors
remained clear and distinct after being kept two months.

Notwithstanding the great variety in the scale of
action of the solar spectrum, the darkening or deoxy-
dizing principle that prevails in the more refrangible
part rarely surpasses or even attains the mean yellow
ray which is the point of maximum illumination ; it is
generally cut off abruptly at that point which seems to
form a limit between the opposing powers which prevail
at the two ends of the spectrum. The bleaching or ox-
ydizing effect of the red rays on blackened muriate of
silver discovered by M. Ritter of Jena, and the restora-

tion by the same rays of discolored gum guaiacum to its original tint by Dr. Wollaston, have already been mentioned as giving the first indications of that difference in the mode of action of the chemical rays at the two ends of the visible spectrum, now placed beyond a doubt.

The action exerted by the less refrangible rays beyond and at the red extremity of the solar spectrum, in most instances, so far from blackening metallic salts, protects them from the action of the diffused daylight; but if the prepared surface has already been blackened by exposure to the sun, they possess the remarkable property of bleaching it in some cases, and under other circumstances of changing the black surface into a fiery red.

Sir John Herschel, to whom we owe most of our knowledge of the properties of the chemical spectrum, prepared a sheet of paper by washing it with muriate of ammonia, and then with two coats of nitrate of silver; on this surface he obtained an impression of the solar spectrum exhibiting a range of colors very nearly corresponding with its natural hues. But a very remarkable phenomenon occurred at the end of least refrangibility; the red rays exerted a protecting influence which preserved the paper from the change which it would otherwise have undergone from the deoxydizing influence of the dispersed light which always surrounds the solar spectrum, and this maintained its whiteness. Sir John met with another instance on paper prepared with bromide of silver, on which the whole of the space occupied by the visible spectrum was darkened down to the very extremity of the red rays, but an oxydizing action commenced beyond the extreme red, which maintained the whiteness of the paper to a considerable distance beyond the last traceable limit of the visible rays, thus evincing decidedly the existence of some chemical power over a considerable space beyond the least refrangible end of the spectrum. Mr. Hunt also found that on the Daguerreotype plate a powerful protecting influence is exercised by the extreme red rays. In these cases the red and those dark rays beyond them exert an action of an opposite nature to that of the violet and lavender rays.

The least refrangible part of the solar spectrum possesses also, under certain circumstances, a bleaching property, by which the metallic salts are restored to their original whiteness after being blackened by exposure to common daylight, or to the most refrangible rays of the solar spectrum.

Paper prepared with iodide of silver, when washed over with ferrocyanite of potash, blackens rapidly when exposed to the solar spectrum. It begins in the violet rays and extends over all the space occupied by the dark chemical rays, and over the whole visible spectrum down to the extreme red rays. This image is colored, the red rays giving a reddish tint and the blue a bluish. In a short time a bleaching process begins under the red rays, and extends upward to the green, but the space occupied by the extreme red is maintained perfectly dark. Mr. Hunt found that a similar bleaching power is exerted by the red rays on paper prepared with protocyanide of potassium and gold with a wash of nitrate of silver.

The application of a moderately strong hydriodate of potash to darkened photographic paper renders it peculiarly susceptible of being whitened by further exposure to light. If paper prepared with bromide of silver be washed with ferrocyanate of potash while under the influence of the solar spectrum, it is immediately darkened throughout the part exposed to the visible rays down to the end of the red, some slight interference being perceptible about the region of the orange and yellow. After this a bleaching action begins over the part occupied by the red rays, which extends to the green. By longer exposure an oval spot begins again to darken about the center of the bleached space; but if the paper receive another wash of the hydriodate of potash, the bleaching action extends up from the green, over the region occupied by the most refrangible rays and considerably beyond them, thus inducing a negative action in the most refrangible part of the spectrum.

In certain circumstances the red rays, instead of restoring darkened photographic paper to its original whiteness, produce a deep red color. When Sir John Herschel received the spectrum on paper somewhat discolored by exposure to direct sunshine, instead of

whiteness, a red border was formed extending from the space occupied by the orange, and nearly covering that on which the red fell. When, instead of exposing the paper in the first instance to direct sunshine, it was blackened by the violet rays of a prismatic spectrum, or by a sunbeam that had undergone the absorptive action of a solution of ammonia-sulphate of copper, the red rays of the condensed spectrum produced on it, not whiteness, but a full and fiery red which occupied the whole space on which any of the visible red rays had fallen, and this red remained unchanged, however long the paper remained exposed to the least refrangible rays.

Sunlight transmitted through red glass produces the same effect as the red rays of the spectrum in the foregoing experiment. Sir John Herschel placed an engraving over a paper blackened by exposure to sunshine, covering the whole with a dark red-brown glass previously ascertained to absorb every ray beyond the orange : in this way a photographic copy was obtained in which the shades were black, as in the original engraving, but the lights, instead of being white, were of the red color of venous blood, and no other color could be obtained by exposure to light, however long. Sir John ascertained that every part of the spectrum impressed by the more refrangible rays is equally reddened, or nearly so, by the subsequent action of the less refrangible ; thus the red rays have the very remarkable property of assimilating to their own color the blackness already impressed on photographic paper.

That there is a deoxydating property in the more refrangible rays, and an oxydating action in the less refrangible part of the spectrum, is manifest from the blackening of one and the bleaching effect of the other; but the peculiar action of the red rays in the experiments mentioned, shows that some other principle exists different from contrariety of action. These opposite qualities are balanced or neutralized in the region of the mean yellow ray. But although this is the general character of the photographic spectrum, under certain circumstances even the red rays have a deoxydating power, while the blue and scarlet exert a contrary influence; but these are rare exceptions.

The photographic action of the two portions of the solar spectrum being so different, Sir John Herschel tried the effect of their united action by superposing the less refrangible part of the spectrum over the more refrangible portion by means of two prisms, and he thus discovered that two rays of different refrangibility, and therefore of different lengths of undulation, acting simultaneously, produce an effect which neither acting separately can do.

Some circumstances that occurred during the analysis of the chemical spectrum seem to indicate an absorptive action in the sun's atmosphere. The spectral image impressed on paper prepared with nitrate of silver and Rochelle salt, commenced at or very little below the mean yellow ray, of a delicate lead color, and when the action was arrested such was the character of the whole photographic spectrum. But when the light of the solar spectrum was allowed to continue its action, there was observed to come on suddenly a new and much more intense impression of darkness, confined in length to the blue and violet rays; and what is most remarkable, confined also in breadth to the middle of the sun's image, so far at least as to leave a border of the lead-colored spectrum traceable, not only round the clear and well-defined convexity of the dark interior spectrum at the least refrangible end, but also laterally along both its edges: and this border was the more easily traced and less liable to be mistaken from its striking contrast of color with the interior spectrum, the former being lead gray, the latter an extremely rich deep velvety brown. The less refrangible end of this interior brown spectrum presented a sharply terminated and regularly elliptical contour, the more refrangible a less decided one. "It may seem too hazardous," Sir John continues, "to look for the cause of this very singular phenomenon in a real difference between the chemical agencies of those rays which issue from the central portion of the sun's disc, and those which, emanating from its borders, have undergone the absorptive action of a much greater depth of its atmosphere; and yet I confess myself somewhat at a loss what other cause to assign for it. It must suffice, however, to have thrown out the hint, re-

marking only, that I have other, and I am disposed to
think decisive, evidence of the existence of an absorptive
solar atmosphere extending beyond the luminous one."
Several circumstances concur in showing that there are
influences also concerned in the transmission of the pho-
tographic action which have not yet been explained, as
for example the influence which the time of the day
exercises on the rapidity with which photographic im-
pressions are made, the sun being much less effective
two hours after passing the meridian than two hours
before. There is also reason to suspect that the effect
in some way depends on the latitude, since a much
longer time is required to obtain an image under the
bright skies of the tropics than in England, and it is
even probable that there is a difference in the sun's
light in high and low latitudes, because an image of the
solar spectrum obtained on a Daguerreotype plate in
Virginia by Dr. Draper, differed from a spectral image
obtained by Mr. Hunt on a similar plate in England.
The inactive spaces discovered in the photographic spec-
trum by M. E. Becquerel similar to those in the lumi-
nous spectrum, and coinciding with them, is also a phe-
nomenon of which no explanation has yet been given.
Although chemical action extends over the whole lumi-
nous spectrum and much beyond it in gradations of
more or less intensity, it is found by careful investiga-
tion to be by no means continuous ; numerous inactive
lines cross it coinciding with those in the luminous image
as far as it extends : besides, a very great number exist
in the portions that are obscure, and which overlap the
visible part. There are three extra-spectral lines be-
yond the red, and some strongly marked groups on the
obscure part beyond the violet ; but the whole number
of those inactive lines, especially in the dark spaces, is
so great that it is impossible to count them.

Notwithstanding this coincidence in the inactive lines
of the two spectra, photographic energy is independent
of both light and heat, since it exerts the most powerful
influence in those rays where they are least, and also
in spaces where neither sensibly exist ; but the trans-
mission of the sun's light through colored media makes
that independence quite evident. Heat and light pass

By reversing the experiment, and exposing different substances to caloric that had already passed through alum, M. Melloni found that the heat emerging from alum is almost totally intercepted by opaque substances, and is abundantly transmitted by all such as are transparent and colorless, and that it suffers no appreciable loss when the thickness of the plate is varied within certain limits.   The properties of the heat therefore which issues from alum, nearly approach to those of light and solar heat.

Radiant heat in traversing various media is not only rendered more or less capable of being transmitted a second time, but, according to the experiments of Professor Powell, it becomes more or less susceptible of being absorbed in different quantities by black or white surfaces.

M. Melloni has proved that solar heat contains rays which are affected by different substances in the same way as if the heat proceeded from a terrestrial source ; whence he concludes that the difference observed between the transmission of terrestrial and solar heat arises from the circumstances of solar heat containing all kinds of caloric, while in other sources some of the kinds are wanting.

Radiant heat, from sources of any temperature whatever, is subject to the same laws of reflection and refraction as rays of light.   The index of refraction from a prism of rock-salt determined experimentally, is nearly the same for light and heat.

Liquids, the various kinds of glass, and probably all substances, whether solid or liquid, that do not crystalize regularly, are more pervious to the calorific rays according as they possess a greater refractive power. For example, the chloride of sulphur, which has a high refractive power, transmits more of the calorific rays than the oils, which have a less refractive power : oils transmit more radiant heat than the acids ; the acids more than aqueous solutions ; and the latter more than pure water, which of all the series has the least refractive power, and is the least pervious to heat.   M. Melloni observed also, that each ray of the solar spectrum follows the same law of action with that of terrestrial rays hav-

Section XXV.

Heat—Calorific Rays of the Solar Spectrum—Experiments of MM. De Laroche and Melloni on the Transmission of Heat—The Point of greatest Heat in the Solar Spectrum varies with the Substance of the Prism—Polarization of Heat—Circular Polarization of Heat—Transmission of the Chemical Rays—Absorption of Heat—Radiation of Heat—Dew—Hoar Frost—Rain—Hail—Combustion—Dilatation of Bodies by Heat—Propagation of Heat—Latent Heat—Heat presumed to consist of the Undulations of an Elastic Medium—Parathermic Rays—Moser's Discoveries.

It is not by vision alone that a knowledge of the sun's rays is acquired, — touch proves that they have the power of raising the temperature of substances exposed to their action. Sir William Herschel discovered that rays of caloric which produce the sensation of heat, exist in the solar spectrum independently of those of light; when he used a prism of flint-glass, he found the warm rays most abundant in the dark space a little beyond the red extremity of the spectrum—that from thence they decrease toward the violet, beyond which they are insensible. It may therefore be concluded, that the calorific rays vary in refrangibility, and that those beyond the extreme red are less refrangible than any rays of light. Since Sir William Herschel's time it has been discovered that the calorific spectrum exceeds the luminous one in length in the ratio of 42 to 25, but the most singular phenomenon of the calorific spectrum is its want of continuity. Sir John Herschel blackened the under side of a sheet of very thin white paper by the smoke of a lamp, and having exposed the white side to the solar spectrum, he drew a brush dipped in spirit of wine over it, by which the paper assumed a black hue when sufficiently saturated. The heat in the spectrum evaporated the spirit first on those parts of the paper where it fell with greatest intensity, thereby restoring their white color, and thus he discovered that the caloric is not distributed uniformly, but in spots of greater or less intensity—a circumstance probably owing to the absorbing action of the atmospheres of the sun and earth. " The effect of the former," says Sir John, " is beyond our control, unless we could carry our experiments to such a point of delicacy as to operate separately

a rays emanating from the center and borders of the
sun's disc; that of the earth's, though it cannot be elim-
nated any more than in the case of the sun's, may yet
)e varied to a considerable extent by experiments made
at great elevations and under a vertical sun, and com-
pared with others where the sun is more oblique, the
situation lower, and the atmospheric pressure of a tem-
porarily high amount. Should it be found that this
cause is in reality concerned in the production of the
spots, we should see reason to believe that a large por-
tion of solar heat never reaches the earth's surface, and
that what is incident on the summits of lofty mountains
differs ·not only in quantity, but also in quality, from
what the plains receive."

Thus the solar spectrum is proved to consist of five
superposed spectra, only three of which are visible—
the red, yellow, and blue; each of the five varies in
refrangibility and intensity throughout the whole ex-
tent, the visible part being overlapped at one extremity
by the chemical, and at the other by the calorific rays;
but the two latter exceed the visible part so much, that
the linear dimensions of the three, the luminous, calo-
rific, and photographic, are in the proportion of the
numbers 25, 42, 10, and 55·10, so that the whole solar
spectrum is more than twice as long as its visible part.

That the heat-producing rays exist independently of
light, is a matter of constant experience in the abundant
emission of them from boiling water. Yet there is
every reason to believe that both the calorific and
chemical rays are modifications of the same agent
which produces the sensation of light. Rays of heat
dart in diverging straight lines from flame, and from
each point in the surfaces of hot bodies, in the same
manner as diverging rays of light proceed from every
point of the surfaces of such as are luminous. Accord-
ing to the experiments of Sir John Leslie, radiation
proceeds not only from the surfaces of substances, but
also from the particles at a minute depth below it. He
found that the emission is most abundant in a direction
perpendicular to the radiating surface, and that it is
more rapid from a rough than from a polished surface:
radiation, however, can only take place in air and in

vacuo; it is altogether imperceptible when the hot body is inclosed in a solid or liquid. Heated substances, when exposed to the open air, continue to radiate caloric till they become nearly of the temperature of the surrounding medium. The radiation is very rapid at first, but diminishes according to a known law with the temperature of the heated body. It appears, also, that the radiating power of a surface is inversely as its reflecting power; and bodies that are most impermeable to heat radiate least.

Rays of heat, whether they proceed from the sun, from flame, or other terrestrial sources, luminous or non-luminous, are instantaneously transmitted through solid and liquid substances, there being no appreciable difference in the time they take to pass through layers of any nature or thickness whatever. They pass also with the same facility whether the media be agitated or at rest; and in these respects the analogy between light and heat is perfect. Radiant heat passes through the gases with the same facility as light; but a remarkable difference obtains in the transmission of light and heat through most solid and liquid substances, the same body being often perfectly permeable to the luminous and altogether impermeable to the calorific rays. For example, thin and perfectly transparent plates of alum and citric acid sensibly transmit all the rays of light from an argand lamp, but stop eight or nine tenths of the concomitant heat; while a large piece of brown rock crystal gives a free passage to the radiant heat, but intercepts almost all the light. M. Melloni has established the general law in uncrystalized substances such as glass and liquids, that the property of instantaneously transmitting heat is in proportion to their refractive powers. The law, however, is entirely at fault in bodies of a crystaline texture. Carbonate of lead, for instance, which is colorless, and possesses a very high refractive power with regard to light, transmits less radiant heat than Iceland spar or rock-crystal, which are very inferior to it in the order of refrangibility; while rock-salt, which has the same transparency and refractive power with alum and citric acid, transmits six or eight times as much caloric. This

remarkable difference in the transmissive power of sub-
stances having the same appearance, is attributed by M.
Melloni to their crystaline form, and not to the chemical
composition of their molecules, as the following experi-
ments prove. A block of common salt cut into plates,
entirely excludes calorific radiation; yet when dissolved
in water, it increases the transmissive power of that
liquid: moreover, the transmissive power of water is
increased in nearly the same degree, whether salt or
alum be dissolved in it; yet these two substances
transmit very different quantities of heat in their solid
state. Notwithstanding the influence of crystalization
on the transmissive power of bodies, no relation has
been traced between that power and the crystaline form.

The transmission of radiant heat is analogous to that
of light through colored media. When common white
light, consisting of blue, yellow, and red rays, passes
through a red liquid, almost all the blue and yellow rays,
and a few of the red, are intercepted by the first layer
of the fluid; fewer are intercepted by the second, still
less by the third, and so on : till at last the losses become
very small and invariable, and those rays alone are
transmitted which give the red color to the liquid. In
a similar manner, when plates of the same thickness of
any substance, such as glass, are exposed to an argand
lamp, a considerable portion of the radiant heat is ar-
rested by the first plate, a less portion by the second,
still less by the third, and so on, the quantity of lost
heat decreasing till at last the loss becomes a constant
quantity. The transmission of radiant heat through a
solid mass follows the same law. The losses are very
considerable on first entering it, but they rapidly dimin-
ish in proportion as the heat penetrates deeper, and
become constant at a certain depth. Indeed, the only
difference between the transmission of radiant heat
through a solid mass, or through the same mass when
cut into plates of equal thickness, arises from the small
quantity of heat that is reflected at the surface of the
plates. It is evident, therefore, that the heat grad-
ually lost is not intercepted at the surface, but absorbed
in the interior of the substance, and that heat which
has passed through one stratum of air experiences a less

14   s 2

absorption in each of the succeeding strata, and may therefore be propagated to a greater distance before it is extinguished. The experiments of M. de Laroche show, that glass, however thin, totally intercepts the obscure rays of caloric when they flow from a body whose temperature is lower than that of boiling water; that as the temperature increases, the calorific rays are transmitted more and more abundantly; and when the body becomes highly luminous, that they penetrate the glass with perfect ease. The extreme brilliancy of the sun is probably the reason why his heat, when brought to a focus by a lens, is more intense than any that has been produced artificially. It is owing to the same cause that glass screens, which entirely exclude the heat of a common fire, are permeable by the solar caloric.

The results obtained by M. de Laroche have been confirmed by the recent experiments of M. Melloni on caloric radiated from sources of different temperatures, whence it appears that the calorific rays pass less abundantly not only through glass, but through rock-crystal, Iceland-spar, and other diaphanous bodies, both solid and liquid, according as the temperature of their origin is diminished, and that they are altogether intercepted when the temperature is about that of boiling water.

In fact, he has proved that the heat emanating from the sun or from a bright flame consists of rays which differ from each other as much as the red, yellow, and blue rays do which constitute white light. This explains the reason of the loss of heat as it penetrates deeper and deeper into a solid mass, or in passing through a series of plates; for, of the different kinds of rays which dart from a vivid flame, all are successively extinguished by the absorbing nature of the substance through which they pass, till those homogeneous rays alone remain which have the greatest facility in passing through that particular substance; exactly as in a red liquid the blue and yellow rays are extinguished, and the red are transmitted.

M. Melloni employed four sources of caloric, two of which were luminous and two obscure; namely, an oil-lamp without a glass, incandescent platina, copper heated to 696°, and a copper vessel filled with water at

ıe temperature of 178½° of Fahrenheit. Rock-salt ꞇansmitted heat in the proportion of 92 rays out of .00 from each of these sources; but all other sub- ꞇances pervious to radiant heat, whether solid or ꞁiquid, transmitted more caloric from sources of high temperature than from such as are low. For instance, limpid and colorless fluate of lime transmitted in the pro- portion of 78 rays out of 100 from. the lamp, 69 from the platina, 42 from the copper, and 33 from the hot water; while transparent rock-crystal transmitted 38 rays in 100 from the lamp, 28 from the platina, 6 from the copper, and 9 from the hot water. Pure ice transmitted only in the proportion of 6 rays in the 100 from the lamp, and entirely excluded those from the other three sources. Out of 39 different substances, 34 were pervious to the calorific rays from hot water, 14 excluded those from the hot copper, and 4 did not transmit those from the platina.

Thus it appears that heat proceeding from these four sources is of different kinds: this difference in the na- ture of the calorific rays is also proved by another ex- periment, which will be more easily understood from the analogy of light. Red light emanating from red glass, will pass in abundance through another piece of red glass, but it will be absorbed by green glass: green rays will more readily pass through a green medium than through one of any other color. This holds with regard to all colors; so in heat. Rays of caloric of the same intensity, which have passed through different substances, are transmitted in different quantities by the same piece of alum, and are sometimes stopped alto- gether; showing that rays which emanate from different substances possess different qualities. It appears that a bright flame furnishes rays of heat of all kinds, in the same manner as it gives light of all colors; and as col- ored media transmit some colored rays and absorb the rest, so bodies transmit some rays of caloric and ex- clude the others. Rock-salt alone resembles colorless transparent media in transmitting all kinds of caloric, even the heat of the hand, just as they transmit white light, consisting of rays of all colors.

The property of transmitting the calorific rays di-

nature of the chemical, visible, and calorific rays. They are all capable of reflection from polished surfaces, of refraction through diaphanous substances, of polarization by reflection and by doubly refracting crystals : none of these rays add sensibly to the weight of matter; their velocity is prodigious ; they may be concentrated and dispersed by convex and concave mirrors; they pass with equal facility through rock-salt, and are capable of radiation; the chemical rays are subject to the same law of interference with those of light; and although the interference of the calorific rays has not yet been proved directly, the indirect evidence places it beyond a doubt. As the action of matter in so many cases is the same on the whole assemblage of rays, visible and invisible, which constitute a solar beam, it is more than probable that the obscure as well as the luminous part is propagated by the undulations of an imponderable ether, and consequently comes under the same laws of analysis.

When radiant heat falls upon a surface, part of it is reflected and part of it is absorbed; consequently the best reflectors possess the least absorbing powers. The temperature of very transparent fluids is not raised by the passage of the sun's rays, because they do not absorb any of them : and as his heat is very intense, transparent solids arrest a very small portion of it. The absorption of the sun's rays is the cause both of the color and temperature of solid bodies. A black substance absorbs all the rays of light and reflects none; and since it absorbs at the same time all the calorific rays, it becomes sooner warm, and rises to a higher temperature than bodies of any other color. Blue bodies come next to black in their power of absorption. Of all the colors of the solar spectrum, the blue possesses least of the heating power; and since substances of a blue tint absorb all the other colors of the spectrum, they absorb by far the greatest part of the calorific rays, and reflect the blue where they are least abundant. Next in order come the green, yellow, red, and last of all, white bodies, which reflect nearly all the rays both of light and heat. However, there are certain limpid and colorless media, which in some cases intercept *calorific radiations* and become heated, while in other

cases they transmit them and undergo no change of temperature.

All substances may be considered to radiate caloric, whatever their temperature may be, though with different intensities, according to their nature, the state of their surfaces, and the temperature of the medium into which they are brought.   But every surface absorbs as well as radiates caloric; and the power of absorption is always equal to that of radiation; for under the same circumstances, matter which becomes soon warm also cools rapidly.   There is a constant tendency to an equal diffusion of caloric, since every body in nature is giving and receiving it at the same instant: each will be of uniform temperature when the quantities of caloric given and received during the same time are equal,— that is, when a perfect compensation takes place between each and all the rest.   Our sensations only measure comparative degrees of heat: when a body, such as ice, appears to be cold, it imparts fewer calorific rays than it receives; and when a substance seems to be warm,—for example, a fire,—it gives more caloric than it takes.   The phenomena of dew and hoar-frost are owing to this inequality of exchange; the caloric radiated during the night by substances on the surface of the earth into a clear expanse of sky is lost, and no return is made from the blue vault, so that their temperature sinks below that of the air, whence they abstract a part of that caloric which holds the atmospheric humidity in solution, and a deposition of dew takes place.   If the radiation be great, the dew is frozen and becomes hoar-frost, which is the ice of dew. Cloudy weather is unfavorable to the formation of dew, by preventing the free radiation of caloric; and actual contact is requisite for its deposition, since it is never suspended in the air like fog.   Plants derive a great part of their nourishment from this source; and as each possesses a power of radiation peculiar to itself, they are capable of procuring a sufficient supply for their wants.   The action of the chemical rays imparts to all substances more or less the power of condensing vapor on those parts on which they fall, and must therefore have a considerable influence on the deposition of dew.

Rain is formed by the mixing of two masses of air of different temperatures; the colder part, by abstracting from the other the heat which holds it in solution, occasions the particles to approach each other and form drops of water, which, becoming too heavy to be sustained by the atmosphere, sink to the earth by gravitation in the form of rain. The contact of two strata of air of different temperatures, moving rapidly in opposite directions, occasions an abundant precipitation of rain. When the masses of air differ very much in temperature, and meet suddenly, hail is formed. This happens frequently in hot plains near a ridge of mountains, as in the south of France; but no explanation has hitherto been given of the cause of the severe hail-storms which occasionally take place on extensive plains within the tropics.

An accumulation of caloric invariably produces light: with the exception of the gases, all bodies which can endure the requisite degree of heat without decomposition begin to emit light at the same temperature; but when the quantity of caloric is so great as to render the affinity of their component particles less than their affinity for the oxygen of the atmosphere, a chemical combination takes place with the oxygen, light and heat are evolved, and fire is produced. Combustion—so essential for our comfort, and even existence—takes place very easily from the small affinity between the component parts of atmospheric air, the oxygen being nearly in a free state; but as the cohesive force of the particles of different substances is very variable, different degrees of heat are requisite to produce their combustion. The tendency of heat to a state of equal diffusion or equilibrium, either by radiation or contact, makes it necessary that the chemical combination which occasions combustion should take place instantaneously; for if the heat were developed progressively, it would be dissipated by degrees, and would never accumulate sufficiently to produce a temperature high enough for the evolution of flame.

It is a general law that all bodies expand by heat and contract by cold. The expansive force of caloric has a *constant* tendency to overcome the attraction of cohesion,

and to separate the constituent particles of solids and fluids; by this separation the attraction of aggregation is more and more weakened, till at last it is entirely overcome, or even changed into repulsion. By the continual addition of caloric, solids may be made to pass into liquids, and from liquids to the aëriform state, the dilatation increasing with the temperature; and every substance expands according to a law of its own. Gases expand more than liquids, and liquids more than solids. The expansion of air is more than eight times that of water, and the increase in the bulk of water is at least forty-five times greater than that of iron. Metals dilate uniformly from the freezing to the boiling points of the thermometer; the uniform expansion of the gases extends between still wider limits; but as liquidity is a state of transition from the solid to the aëriform condition, the equable dilatation of liquids has not so extensive a range. This change of bulk, corresponding to the variation of heat, is one of the most important of its effects, since it furnishes the means of measuring relative temperature by the thermometer and pyrometer. The rate of expansion of solids varies at their transition to liquidity, and that of liquidity is no longer equable near their change to an aëriform state. There are exceptions however to the general laws of expansion; some liquids have a maximum density corresponding to a certain temperature, and dilate whether that temperature be increased or diminished. For example —water expands whether it be heated above or cooled below 40°. The solidification of some liquids, and especially their crystalization, is always accompanied by an increase of bulk. Water dilates rapidly when converted into ice, and with a force sufficient to split the hardest substances. The formation of ice is therefore a powerful agent in the disintegration and decomposition of rocks, operating as one of the most efficient causes of local changes in the structure of the crust of the earth; of which we have experience in the tremendous *éboulements* of mountains in Switzerland.

The dilatation of substances by heat, and their contraction by cold, occasion such irregularities in the rate of clocks and watches as would render them unfit for astronomical or nautical purposes, were it not for a very

beautiful application of the laws of unequal expansion.
The oscillations of a pendulum are the same as if its
whole mass were united in one dense particle, in a cer-
tain point of its length, called the center of oscillation.
If the distance of this point from the point by which the
pendulum is suspended were invariable, the rate of the
clock would be invariable also.   The difficulty is to neu-
tralize the effects of temperature, which is perpetually
increasing or diminishing its length.   Among many con-
trivances, Graham's compensation pendulum is the most
simple.   He employed a glass tube containing mercury.
When the tube expands from the effects of heat, the
mercury expands much more; so that its surface rises
a little more than the end of the pendulum is depressed,
and the center of oscillation remains stationary.   Har-
rison invented a pendulum which consists of seven bars
of steel and of brass, joined in the shape of a gridiron,
in such a manner that if by change of temperature the
bars of brass raise the weight at the end of the pendu-
lum, the bars of steel depress it as much.   In general,
only five bars are used; three being of steel and two a
mixture of silver and zinc.   The effects of temperature
are neutralized in chronometers upon the same princi-
ple; and to such perfection are they brought, that the
loss or gain of one second in twenty-four hours for two
days running would render one unfit for use.   Accuracy
in surveying depends upon the compensation rods em-
ployed in measuring bases.   Thus, the laws of the une-
qual expansion of matter judiciously applied have an
immediate influence upon our estimation of time; of
the motions of bodies in the heavens, and of their fall
upon the earth; on our determination of the figure of
the globe, and on our system of weights and measures;
on our commerce abroad, and the mensuration of our
lands at home.

   The expansion of the crystaline substances takes place
under very different circumstances from the dilatation
of such as are not crystalized.   The latter become both
longer and thicker by an acession of heat, whereas M.
Mitscherlich has found that the former expand differ-
ently in different directions; and in a particular instance,
extension in one direction is accompanied by contraction

in another.   The internal structure of crystalized mat-
ter must be very peculiar, thus to modify the expansive
power of heat, and so materially to influence the trans-
mission of caloric and the visible rays of the spectrum.

Heat is propagated with more or less rapidity through
all bodies ; air is the worst conductor, and consequently
mitigates the severity of cold climates by preserving the
heat imparted to the earth by the sun.   On the con-
trary, dense bodies, especially metals, possess the power
of conduction in the greatest degree, but the transmis-
sion requires time.   If a bar of iron twenty inches long
be heated at one extremity, the caloric takes four min-
utes in passing to the other.   The particle of the metal
that is first heated communicates its caloric to the sec-
ond, and the second to the third ; so that the temperature
of the intermediate molecule at any instant is increased
by the excess of the temperature of the first above its
own, and diminished by the excess of its own tempera-
ture above that of the third.   That however will not
be the temperature indicated by the thermometer, be-
cause as soon as the particle is more heated than the
surrounding atmosphere, it loses its caloric by radiation,
in proportion to the excess of its actual temperature
above that of the air.   The velocity of the discharge is
directly proportional to the temperature, and inversely
as the length of the bar.   As there are perpetual varia-
tions in the temperature of all terrestrial substances and
of the atmosphere, from the rotation of the earth, and
its revolution round the sun, from combustion, friction,
fermentation, electricity, and an infinity of other causes,
the tendency to restore the equability of temperature
by the transmission of caloric must maintain all the
particles of matter in a state of perpetual oscillation,
which will be more or less rapid according to the con-
ducting powers of the substances.   From the motion of
the heavenly bodies about their axes, and also round the
sun, exposing them to perpetual changes of temperature,
it may be inferred that similar causes will produce like
effects in them too.   The revolutions of the double stars
show that they are not at rest ; and though we are to-
tally ignorant of the changes that may be going on in the
nebulæ and millions of other remote bodies, it is hardly

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possible that they should be in absolute repose; so that, as far as our knowledge extends, motion seems to be a law of matter.

Heat applied to the surface of a fluid is propagated downward very slowly, the warmer and consequently lighter strata always remaining at the top. This is the reason why the water at the bottom of lakes fed from alpine chains is so cold; for the heat of the sun is transfused but a little way below the surface. When heat is applied below a liquid, the particles continually rise as they become specifically lighter in consequence of the caloric, and diffuse it through the mass, their place being perpetually supplied by those that are more dense. The power of conducting heat varies materially in different liquids. Mercury conducts twice as fast as an equal bulk of water, which is the reason why it appears to be so cold. A hot body diffuses its caloric in the air by a double process. The air in contact with it being heated and becoming lighter, ascends and scatters its caloric, while at the same time another portion is discharged in straight lines by the radiating powers of the surface. Hence a substance cools more rapidly in air than in vacuo, because in the latter case the process is carried on by radiation alone. It is probable that the earth, having originally been of very high temperature, has become cooler by radiation only. The ethereal medium must be too rare to carry off much caloric.

Besides the degree of heat indicated by the thermometer, caloric pervades bodies in an imperceptible or latent state; and their capacity for heat is so various, that very different quantities of caloric are required to raise different substances to the same sensible temperature; it is therefore evident that much of the caloric is absorbed, or becomes latent and insensible to the thermometer. The portion of caloric requisite to raise a body to a given temperature is its specific heat; but latent heat is that portion of caloric which is employed in changing the state of bodies from solid to liquid, and from liquid to vapor. When a solid is converted into a liquid, a greater quantity of caloric enters into it than can be detected by the thermometer; this accession of caloric does not make the body warmer, though it converts it into a liquid, and

is the principal cause of its fluidity.   Ice remains at the
temperature of 32° of Fahrenheit till it has combined
with or absorbed 140° of caloric, and then it melts, but
without raising the temperature of the water above 32°;
so that water is a compound of ice and caloric.   On
the contrary, when a liquid is converted into a solid, a
quantity of caloric leaves it without any diminution of
temperature.   Water at the temperature of 32° must
part with 140° of caloric before it freezes.   The slow-
ness with which water freezes, or ice thaws, is a con-
sequence of the time required to give out or absorb 140°
of latent heat.   A considerable degree of cold is often felt
during a thaw, because the ice, in its transition from a
solid to a liquid state, absorbs sensible heat from the atmos-
phere and other bodies, and by rendering it latent main-
tains them at the temperature of 32° while melting.   Ac-
cording to the same principle, vapor is a combination of
caloric with a liquid.   By the continued application of
heat, liquids are converted into vapor or steam, which
is invisible and elastic like common air.   Under the
ordinary pressure of the atmosphere, that is, when the
barometer stands at 30 inches, water acquires a constant
accession of heat till its temperature rises to 212° of
Fahrenheit; after that it ceases to show any increase
in heat, but when it has absorbed an additional 1000° of
caloric it is converted into steam.   Consequently, about
1000° of latent heat exists in steam without raising its
temperature, and steam at 212° must part with the same
quantity of latent caloric when condensed into water.
Water boils at different temperatures under different
degrees of pressure.   It boils at a lower temperature
on the top of a mountain than in the plain below,
because the weight of the atmosphere is less at the
higher station.   There is no limit to the temperature
to which water might be raised; it might even be made
red-hot, could a vessel be found strong enough to resist
the pressure.   The expansive force of steam is in pro-
portion to the temperature at which the water boils; it
may therefore be increased to a degree that is only lim-
ited by our inability to restrain it, and is the greatest
power that has been made subservient to the wants of
man.

It is found that the absolute quantity of heat consumed in the process of converting water into steam is the same at whatever temperature water may boil, but that the latent heat of steam is always greater exactly in the same proportion as its sensible heat is less. Steam raised at 212° under the ordinary pressure of the atmosphere, and steam raised at 180° under half that pressure, contain the same quantity of heat, with this difference, that the one has more latent heat and less sensible heat than the other. It is evident that the same quantity of heat is requisite for converting a given weight of water into steam, at whatever temperature or under whatever pressure the water may be boiled; and therefore in the steam engine, equal weights of steam at a high pressure and a low pressure are produced by the same quantity of fuel; and whatever the pressure of the steam may be, the consumption of fuel is proportional to the quantity of water converted into vapor. Steam at a high pressure expands as soon as it comes into the air, by which some of its sensible heat becomes latent; and as it naturally has less sensible heat than steam raised under low pressure, its actual temperature is reduced so much that the hand may be plunged into it without injury the instant it issues from the orifice of a boiler.

The elasticity or tension of steam, like that of common air, varies inversely as its volume; that is, when the space it occupies is doubled, its elastic force is reduced one-half. The expansion of steam is indefinite; the smallest quantity of water when reduced to the form of vapor, will occupy many millions of cubic feet; a wonderful illustration of the minuteness of the ultimate particles of matter! The latent heat absorbed in the formation of steam is given out again by its condensation.

Steam is formed throughout the whole mass of a boiling liquid, whereas evaporation takes place only at the free surfaces of liquids, and that under the ordinary temperature and pressure of the atmosphere. There is a constant evaporation from the land and water all over the earth. The rapidity of its formation does not altogether depend upon the dryness of the air; according to Dr. Dalton's experiments, it depends also on the dif-*ference between* the tension of the vapor which is form-

ing and that which is already in the atmosphere. In calm weather, vapor accumulates in the stratum of air immediately above the evaporating surface, and retards the formation of more; whereas a strong wind accelerates the process, by carrying off the vapor as soon as it rises, and making way for a succeeding portion of dry air.

The latent heat of air and all elastic fluids may be forced out by sudden compression, like squeezing water out of sponge. The quantity of heat brought into action in this way is very well illustrated in the experiment of igniting a piece of timber by the sudden compression of air by a piston thrust into a cylinder closed at one end: the development of heat on a stupendous scale is exhibited in lightning, probably produced in part by the violent compression of the atmosphere during the passage of the electric fluid. Prodigious quantities of heat are constantly becoming latent, or are disengaged by the changes of condition to which substances are liable in passing from the solid to the liquid, and from the liquid to the gaseous form, or the contrary, occasioning endless vicissitudes of temperature over the globe.

There are many other sources of heat, such as combustion, friction, and percussion, all of which are only means of calling a power into evidence which already exists.

The application of heat to the various branches of the mechanical and chemical arts has, within a few years, effected a greater change in the condition of man than had been accomplished in any equal period of his existence. Armed by the expansion and condensation of fluids with a power equal to that of the lightning itself, conquering time and space, he flies over plains, and travels on paths cut by human industry even through mountains, with a velocity and smoothness more like planetary than terrestrial motion; he crosses the deep in opposition to wind and tide; by releasing the strain on the cable, he rides at anchor fearless of the storm; he makes the elements of air and water the carriers of warmth, not only to banish winter from his home, but to adorn it even during the snow-storm with the blossoms of spring; and, like a magician, he raises, from the gloomy and

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deep abyss of the mine, the spirit of light to dispel the midnight darkness.

It has been observed that heat, like light and sound, probably consists in the undulations of an elastic medium. All the principal phenomena of heat may actually be illustrated by a comparison with those of sound. The excitation of heat and sound are not only similar but often identical, as in friction and percussion; they are both communicated by contact and radiation; and Dr. Young observes, that the effect of radiant heat in raising the temperature of a body upon which it falls, resembles the sympathetic agitation of a string when the sound of another string which is in unison with it is transmitted through the air. Light, heat, sound, and the waves of fluids, are all subject to the same laws of reflection, and indeed their undulatory theories are perfectly similar. If, therefore, we may judge from analogy, the undulations of some of the heat-producing rays must be less frequent than those of the extreme red of the solar spectrum; but the analogy is now perfect, since the interference of heat is no longer a matter of doubt: hence the interference of two hot rays must produce cold; darkness results from the interference of two undulations of light; silence ensues from the interference of two undulations of sound; and still water, or no tide, is the consequence of the interference of two tides. The propagation of sound, however, requires a much denser medium than that either of light or heat; its intensity diminishes as the rarity of the air increases; so that, at a very small height above the surface of the earth, the noise of the tempest ceases, and the thunder is heard no more in those boundless regions where the heavenly bodies accomplish their periods in eternal and sublime silence.

A consciousness of the fallacy of our senses is one of the most important consequences of the study of nature. This study teaches us that no object is seen by us in its true place, owing to aberration; that the colors of substances are solely the effects of the action of matter upon light; and that light itself, as well as heat and sound, are not real beings, but mere modes of action communicated to our perceptions by the nerves. The human frame

may therefore be regarded as an elastic system, the different parts of which are capable of receiving the tremors of elastic media, and of vibrating in unison with any number of superposed undulations, all of which have their perfect and independent effect. Here our knowledge ends; the mysterious influence of matter on mind will in all probability be forever hid from man.

A series of experiments by Sir John Herschel has disclosed a new set of obscure rays in the solar spectrum, which seem to bear the same relation to those of heat that the photographic or chemical rays bear to the luminous. They are situate in that part of the spectrum which is occupied by the less refrangible visible colors, and have been named by their discoverer Parathermic rays. It must be held in remembrance that the region of greatest heat in the solar spectrum lies in the dark space beyond the visible red. Now Sir John Herschel found that in experiments with a solution of gum guaiacum in soda, which gives the paper a green color, the green, yellow, orange, and red rays of the spectrum invariably discharged the color, while no effect was produced by the extra-spectral rays of caloric, which ought to have had the greatest effect, had heat been the cause of the phenomenon. When an aqueous solution of chlorine was poured over a slip of paper prepared with gum guaiacum dissolved in soda, a color varying from a deep somewhat greenish hue to a fine celestial blue was given to it; and when the solar spectrum was thrown on the paper while moist, the color was discharged from all the space under the less refrangible luminous rays, at the same time that the more distant thermic rays beyond the spectrum evaporated the moisture from the space on which they fell: so that the heat spots became apparent. But the spots disappeared as the paper dried, leaving the surface unchanged; while the photographic impression within the visible spectrum increased in intensity, the non-luminous thermic rays, though evidently active *as to heat*, were yet incapable of effecting that peculiar chemical change which other rays of much less heating power were all the time producing. Sir John having ascertained that an artificial heat from 180° to 280° of Fahrenheit changed the green tint of

gum guaiacum to its original yellow hue when moist, but that it had no such effect when dry, he therefore tried whether heat from a hot iron applied to the back of the paper used in the last-mentioned experiment while under the influence of the solar spectrum might not assist the action of the calorific rays; but instead of doing so, it greatly accelerated the discoloration over the spaces occupied by the less refrangible rays, but had no effect on the extra-spectral region of maximum heat. Obscure terrestrial heat therefore is capable of assisting and being assisted in effecting this peculiar change by those rays of the spectrum, whether luminous or thermic, which occupy its red, yellow, and green regions, while on the other hand it receives no such assistance from the purely thermic rays beyond the spectrum acting under similar circumstances and in an equal state of condensation.

The conclusions drawn from these experiments are confirmed by that which follows: a photographic picture formed on paper prepared with a mixture of the solutions of ammonia-citrate of iron and ferro-sesquicyanite of potash in equal parts, then thrown into water and afterward dried, will be blue and negative, that is to say, the lights and shadows will be the reverse of what they are in nature. If in this state the paper be washed with a solution of proto-nitrate of mercury, the picture will be discharged: but if it be well washed and dried and a hot smoothing iron passed over it, the picture instantly reappears, not blue, but brown: if kept some weeks in this state in perfect darkness between the leaves of a portfolio, it fades and almost entirely vanishes, but a fresh application of heat restores it to its full original intensity. This curious change is not the effect of light, at least not of light alone. A certain temperature must be attained, and that suffices in total darkness: yet on exposing to a very concentrated spectrum a slip of the paper used in the last experiment, after the uniform blue color has been discharged and a white ground left, this whiteness is changed to brown over the whole region of the red and orange rays, *but not beyond* the luminous spectrum.

Sir John thence concludes—1st. That it is the heat

of these rays, not their light, which operates the change; 2dly. That this heat possesses a peculiar chemical quality which is not possessed by the purely calorific rays outside of the visible spectrum, though far more intense; and, 3dly. That the heat radiated from obscurely hot iron, abounds especially in rays analogous to those of the region of the spectrum above indicated.

Another instance of these singular transformations may be noticed. The pictures formed on cyanotype paper, rendered more sensitive by the addition of corrosive sublimate, are blue on a white ground and positive, that is, the lights and shadows are the same as in nature, but by the application of heat, the color is changed from blue to brown, from positive to negative; even by keeping in darkness the blue color is restored, as well as the *positive character*. Sir John attributes this as in the former instance to certain rays, which regarded as rays of heat or light, or of some influence *sui generis* accompanying the red and orange rays of the spectrum, are also copiously emitted by bodies heated short of redness. He thinks it probable that these invisible parathermic rays are the rays which radiate from molecule to molecule in the interior of bodies, that they determine the discharge of vegetable colors at the boiling temperature, and also the innumerable atomic transformations of organic bodies which take place at the temperature below redness, that they are distinct from those of pure heat, and that they are sufficiently identified by these characters to become legitimate objects of scientific discussion.

The calorific and parathermic rays appear to be so intimately connected with the discoveries of Messrs. Draper and Moser that the subject of solar radiation would be imperfect were they omitted. The discovery of Daguerre shows that the action of light on the iodide of silver renders it capable of condensing the vapor of mercury which adheres to the parts affected by it. Professor Moser of Königsberg has proved that the same effect is produced by the simple contact of bodies, and even by their very near juxta-position, and that in total darkness as well as in light. This discovery he announced in the following words: "If a

surface has been touched in any particular parts by any body, it acquires the property of precipitating all vapors, and these adhere to it or combine chemically with it on those spots differently to what they do on the untouched parts." If we write on a plate of glass or any smooth surface whatever with blotting paper, a brush, or anything else, and then clean it, the characters always reappear if the plate or surface be breathed upon, and the same effect may be produced even on the surface of mercury; nor is absolute contact necessary. If a screen cut in a pattern be held over a polished metallic surface at a small distance, and the whole breathed on: after the vapor has evaporated so that no trace is left on the surface, the pattern comes out when it is breathed on again.

Professor Moser proved that bodies exert a very decided influence upon each other, by placing coins, cut stones, pieces of horn, and other substances, a short time on a warm metallic plate; when the substance was removed no impression appeared on the plate till it was breathed upon or exposed to the vapor of mercury, and then these vapors adhered only to the parts where the substance had been placed, making distinct images, which in some cases were permanent after the vapor was removed. Similar impressions were obtained on glass and other substances even when the bodies were not in contact, and the results were the same whether the experiments were performed in light or in darkness.

Mr. Hunt has shown that many of these phenomena depend on difference of temperature, and that in order to obtain good impressions dissimilar metals must be used. For example, gold, silver, bronze, and copper coins were placed on a plate of copper too hot to be touched, and allowed to remain till the plate cooled; all the coins had made an impression, the distinctness and intensity of which was in the order of the metals named. When the plate was exposed to the vapor of mercury the result was the same, but when the vapor was wiped off, the gold and silver coins only had left permanent images on the copper. These impressions are often minutely perfect whether the coins are in actual contact with the plate or ¼ of an inch above it.

The mass of the metal has a material influence on the result; a large copper coin makes a better impression on a copper plate than a small silver coin. When coins of different metals are placed on the same plate they interfere with each other.

When, instead of being heated, the copper plate was cooled by a freezing mixture, and bad conductors of heat laid upon it, as wood, paper, glass, &c., the result was similar, showing that the phenomena could be produced by any disturbance of the caloric latent in the substances.

There can be no doubt that these phenomena are universal, since all substances are more or less sensitive to light, which must produce innumerable changes in the nature of terrestrial things, especially in the vegetable tribe, by the power it gives of condensing vapor and consequently the deposition of dew.

Red and orange-colored media, smoked glass, and all bodies that transmit or absorb the calorific rays freely, leave strong impressions on a plate of copper whether they be in contact or $\frac{1}{8}$ of an inch above the plate. The strongest proof that heat is concerned in some at least of these phenomena is evident. For instance, a solar spectrum concentrated by a lens was thrown on a polished plate of copper and kept on the same spot by a heliostat for one, two, or three hours; when exposed to mercurial vapor a film of the vapor covered the plate where the diffused light which always accompanies the solar spectrum had fallen; on the obscure space occupied by the maximum heating power of Sir William Herschel, and also the great heat spot in the thermic spectrum of Sir John Herschel, the condensation of the mercury was so thick that it stood out a distinct white spot on the plate, while over the whole space that had been under the visible spectrum the quantity of vapor was much less than that which covered the other parts, affording distinct evidence of a negative effect in the luminous spectrum, and of the power of the calorific rays, which is not always confined to the surface of the metal, since in many instances the impressions are formed to a considerable depth below it, and consequently are permanent.

Mr. Hunt observing that a black substance leaves a stronger impression on a metallic surface than a white, applied the property to the art of thermography, by which he copies prints, wood-cuts, writing, and printing, on copper amalgamated on one surface and highly polished, merely by placing the object to be copied smoothly on the metal and pressing it into close contact by a plate of glass: after some hours the plate is subjected to the vapor of mercury and afterward to that of iodine, when a black and accurate impression of the object comes out on a gray ground. Effects similar to those attributed to heat may also be produced by electricity: Mr. Karsten, by placing a glass plate upon one of metal, and on the glass plate a medal subjected to discharges of electricity, found a perfect image of the medal impressed on the glass, which could be brought into evidence by either mercury or iodine; and when several plates of glass were interposed between the medal and the metallic plate, each plate of glass received an image on its upper surface after the passage of electrical discharges. These discharges have the remarkable power of restoring impressions that have been long obliterated from plates by polishing; a proof that the disturbances upon which these phenomena depend are not confined to the surface of the metals, but that a very decided molecular change has taken place to a considerable depth. Mr. Hunt's experiments prove that the electro-negative metals make the most decided images upon electro-negative plates, and *vice versâ*. M. Matteucci has shown that a discharge of electricity does not visibly affect a polished silver plate, but that it produces an alteration which renders it capable of condensing vapor.

M. Fizeau ascribes a numerous class of these phenomena to the action of a slight layer of organic or fatty matter on the surfaces, which, being volatile, is transferred to any body near, in a greater or less quantity according to the distance; that is, according as the surface projects or sinks into hollows. When the different parts of a surface are unequally soiled by extraneous bodies, even in the minutest quantity, the condensation of mercurial vapor is effected in a manner visibly dif-

ferent on its different parts, and therefore images are
formed.   Although this explains various phenomena, it
does not apply to those already described, as Mr. Hunt
had taken the precaution to divest the substances he
used of every trace of organic matter.

It is difficult to see to what cause Mr. Hunt's experi-
ments on the reciprocal action of bodies in total darkness
can be attributed, unless perhaps to a constant radiation
of some peculiar principle from their surfaces, which
really seems to exist.

The impression of an engraving was made by laying
it face downwards on a silver plate iodized, and placing
an amalgamated copper plate upon it: it was left in
darkness fifteen hours, when an impression of the en-
graving had been made on the amalgamated plate,
through the paper.

As the same may be obtained on plates of iron, zinc,
or lead, it is evident that this result is not the effect of
chemical rays.

An iodized silver plate was placed in darkness with a
coil of string laid on it, and with a polished silver plate
suspended one eighth of an inch above it; after four
hours they were exposed to the vapors of mercury,
which became uniformly deposited on the iodized plate,
but on the silver one there was a sharp image of the
string, so that this image was formed in the dark, and
even without contact. Coins or other objects leave
their impressions in the same manner with perfect
sharpness and accuracy, when brought out by vapor
without contact, in darkness, and on simple metals.

Heat, electricity, and the evaporation of unctuous
matter, may account for some of these phenomena, but
others clearly point at some unknown influence exerted
between the surfaces of solid bodies, and affecting their
molecular structure so as to determine the precipitation
of vapors, an influence which in all probability will ulti-
mately be found to be either the parathermic rays of
Sir John Herschel, or intimately connected with them.

Section XXVI.

THE ocean of light and heat perpetually flowing from
the sun, must affect the bodies of the system very differ-
ently, on account of the varieties in their atmospheres,
some of which appear to be very extensive and dense.
According to the observations of Schröeter, the atmos-
phere of Ceres is more than 668 miles high, and that of
Pallas has an elevation of 465 miles.   These must re-
fract the light and prevent the radiation of heat like our
own.   But it is remarkable that not a trace of atmosphere
can be perceived in Vesta.   The action of the sun's rays
must be very different on such bodies from what it is
on the earth, and the heat imparted to them quickly
lost by radiation; yet it is impossible to estimate their
temperature, since the cold may be counteracted by
their central heat, if, as there is reason to presume, they
have originally been in a state of fusion, possibly of
vapor.   The attraction of the earth has probably de-
prived the moon of hers; for the refractive power of
the air at the surface of the earth is at least a thousand
times as great as refraction at the surface of the moon.
The lunar atmosphere, therefore, must be of a greater
degree of rarity than can be produced by our best air-
pumps; consequently no terrestrial animal could exist
in it.   This was confirmed by M. Arago's observations
during the last great solar eclipse, when no trace of a
lunar atmosphere was to be seen.

The sun has a very dense atmosphere, which is
probably the cause of the peculiar phenomena in his
photographic image already mentioned.   What his body
may be, it is impossible to conjecture; but he seems to

be surrounded by a mottled ocean of flame, through which his dark nucleus appears like black spots often of enormous size. These spots are almost always comprised within a zone of the sun's surface, whose breadth, measured on a solar meridian, does not extend beyond $30\frac{1}{2}°$ on each side of his equator, though they have been seen at the distance of $39\frac{1}{2}°$. From their extensive and rapid changes, there is every reason to suppose that the exterior and incandescent part of the sun is gaseous. The solar rays, probably arising from chemical processes that continually take place at his surface, or from electricity, are transmitted through space in all directions; but notwithstanding the sun's magnitude, and the inconceivable heat that must exist at his surface, as the intensity both of his light and heat diminishes as the square of the distance increases, his kindly influence can hardly be felt at the boundaries of our system, or at all events it must be but feeble.

The direct light of the sun has been estimated to be equal to that of 5563 wax candles of moderate size, supposed to be placed at the distance of one foot from the object. That of the moon is probably only equal to the light of one candle at the distance of twelve feet. Consequently the light of the sun is more than three hundred thousand times greater than that of the moon. Hence the light of the moon imparts no heat. Professor Forbes is convinced by recent experiments that the direct light of the moon is incapable of raising a thermometer one three-hundred-thousandth part of a centigrade degree, at least in this climate. The intensity of the sun's light diminishes from the center to the circumference of the solar disc.

In Uranus, the sun must be seen like a small but brilliant star, not above the hundred and fiftieth part so bright as he appears to us; but that is 2000 times brighter than our moon; so that he is really a sun to Uranus, and may impart some degree of warmth. But if we consider that water would not remain fluid in any part of Mars, even at his equator, and that in the temperate zones of the same planet even alcohol and quicksilver would freeze, we may form some idea of the cold that must reign in Uranus.

The climate of Venus more nearly resembles that of the earth, though, excepting perhaps at her poles, much too hot for animal and vegetable life as they exist here; but in Mercury, the mean heat arising only from the intensity of the sun's rays must be above that of boiling quicksilver, and water would boil even at his poles. Thus the planets, though kindred with the earth in motion and structure, are totally unfit for the habitation of such a being as man, unless, indeed, their temperature should be modified by circumstances of which we are not aware, and which may increase or diminish the sensible heat so as to render them habitable.

It is found by experience, that heat is developed in opaque and translucent substances by their absorption of solar light, but that the sun's rays do not sensibly alter the temperature of perfectly transparent bodies through which they pass. As the temperature of the pellucid planetary space can be but little affected by the passage of the sun's light and heat, neither can it be sensibly raised by the heat now radiated from the earth; consequently its temperature must be invariable, at least throughout the extent of the solar system. The atmosphere, on the contrary, gradually increasing in density toward the surface of the earth, becomes less pellucid, and therefore gradually increases in temperature, both from the direct action of the sun, and from the radiation of the earth. Lambert had proved that the capacity of the atmosphere for heat varies according to the same law with its capacity for absorbing a ray of light passing through it from the zenith, whence M. Svanberg found that the temperature of space is 58° below the zero point of Fahrenheit's thermometer. From other researches, founded upon the rate and quantity of atmospheric refraction, he obtained a result which only differs from the preceding by half a degree. M. Fourier has arrived at nearly the same conclusion from the law of the radiation of the heat of the terrestrial spheroid, on the hypothesis of its having nearly attained its limit of temperature in cooling down from its supposed primitive state of fusion. The difference in the result of these three methods, totally independent of one another, *only amounts* to the fraction of a degree.

The cold endured by Sir Edward Parry one day in Melville Island was 55° below zero; and that suffered by Captain Back on the 17th of January, 1834, in 62° 46½′ of north latitude, was no less than 70° below the same point. However, M. Poisson attributes this to accidental circumstances, and by a recent computation, he makes the temperature of space to be 8° above the zero of Fahrenheit. This he considers greatly to exceed the temperature of the exterior strata of the atmosphere, which he conceives to be deprived of their elasticity by intense cold, and he thus accounts for the decrease of temperature at great elevations, and for the limited extent of the atmosphere.

Doubtless, the radiation of all the bodies in the universe maintains the ethereal medium at a higher temperature than it would otherwise have, and must eventually increase it, but by a quantity so evanescent that it is hardly possible to conceive a time when a change will become perceptible.

The temperature of space being so low, it becomes a matter of no small interest to ascertain whether the earth may not be ultimately reduced by radiation to the temperature of the surrounding medium; what the sources of heat are; and whether they be sufficient to compensate the loss, and to maintain the earth in a state fit for the support of animal and vegetable life in time to come. All observations that have been made under the surface of the ground concur in proving that there is a stratum at the depth of from 40 to 100 feet throughout the whole earth, where the temperature is invariable at all times and seasons, and which differs but little from the mean annual temperature of the country above. According to M. Boussingault, indeed, that stratum at the equator is at the depth of little more than a foot in places sheltered from the direct rays of the sun; but in our climates it is at a much greater depth. In the course of more than half a century, the temperature of the earth at the depth of 90 feet in the caves of the Observatory at Paris has never been above or below 53° of Fahrenheit's thermometer, which is only 2° above the mean annual temperature at Paris. This zone, unaffected by the sun's rays from above, or by the internal heat from below,

5° or 6°, and that if the heat could be attributed to this cause, the seasons would sensibly affect the temperature of mines, which it appears they do not where the depth is great.   Besides, the Cornish mines are generally ventilated by numerous shafts opening into the galleries from the surface or from a higher level.   The air circulates freely in these, descending in some shafts and ascending in others.   In all cases, Mr. Fox found that the upward currents are of a higher temperature than the descending currents ; so much so, that in winter the moisture is often frozen in the latter to a considerable depth ; the circulation of air, therefore, tends to cool the mine instead of increasing the heat.   Mr. Fox has also removed the objections arising from the comparatively low temperature of the water in the shafts of abandoned mines, by showing that observations in them, from a variety of circumstances which he enumerates, are too discordant to furnish any conclusion as to the actual heat of the earth.   The high temperature of mines might be attributed to the effects of the fires, candles, and gunpowder used by the miners, did not a similar increase obtain in deep wells, and in borings to great depths in search of water, where no such causes of disturbance occur.   In a well dug with a view to discover salt in the canton of Berne, and long deserted, M. de Saussure had the most complete evidence of increasing heat.   The same has been confirmed by the temperature of many wells, both in France and England, especially by the Artesian wells, so named from a peculiar method of raising water first resorted to in Artois, and since become very general.   An Artesian well consists of a shaft of a few inches in diameter, bored into the earth till a spring is found.   To prevent the water being carried off by the adjacent strata, a tube is let down which exactly fills the bore from top to bottom, in which the water rises pure to the surface.   It is clear the water could not rise unless it had previously descended from high ground through the interior of the earth to the bottom of the well.   It partakes of the temperature of the strata through which it passes, and in every instance has been warmer in proportion to the depth of the well ; but it is evident that the law of in-

crease cannot be obtained in this manner. Perhaps the most satisfactory experiments on record are those made by MM. August de la Rive and F. Marcet during the year 1833, in a boring for water about a league from Geneva, at a place 318 feet above the level of the lake. The depth of the bore was 727 feet, and the diameter only between four and five inches. No spring was ever found; but the shaft filled with mud, from the moisture of the ground mixing with the earth displaced in boring, which was peculiarly favorable for the experiments, as the temperature at each depth may be considered to be that of the particular stratum. In this case, where none of the ordinary causes of disturbance could exist, and where every precaution was employed by scientific and experienced observers, the temperature was found to increase regularly and uniformly with the depth at the rate of about 1° of Fahrenheit for every 52 feet. Professor Reich of Freyberg has found that the mean of a great number of observations both in mines and wells is 1° of Fahrenheit for every 55 feet of depth, and from M. Arago's observations in an Artesian well now boring in Paris, the increase is 1° of Fahrenheit for every 45 feet. Though there can be no doubt as to the increase of temperature in penetrating the crust of the earth, there is still much uncertainty as to the law of increase, which varies with the nature of the soil and other local circumstances; but on an average, it has been estimated at the rate of 1° for every 50 or 60 feet, which corresponds with the observations of MM. Marcet and de la Rive. In consequence of the rapid increase of internal heat, thermal springs, or such as are independent of volcanic action, rising from a great depth, must necessarily be very rare and of a high temperature, and it is actually found that none are so low as 68° of Fahrenheit: that of Chaudes Aigues in Auvergne is about 136°. In many places warm water from Artesian wells will probably come into use for domestic purposes, and it is even now employed in manufactories at Wurtemberg, in Alsace, and near Stutgardt.

It is hardly to be expected that at present any information with regard to the actual internal temperature *of the earth* should be obtained from that of the ocean,

on account of the mobility of fluids, by which the colder masses sink downward, while those that are warmer rise to the surface.   Nevertheless it may be stated, that the temperature of the sea decreases with the depth between the tropics; while on the contrary, all our northern navigators found that the temperature increases with the depth in the polar seas.   The change takes place about the 70th parallel of latitude.   Some ages hence, however, it may be known whether the earth has arrived at a permanent state as to heat, by comparing secular observations of the temperature of the ocean if made at a great distance from the land.

Should the earth's temperature increase at the rate of 1° for every fifty feet, it is clear that at the depth of 200 miles the hardest substances must be in a state of fusion, and our globe must in that case either be encompassed by a stratum of melted lava at that depth, or it must be a ball of liquid fire 7600 miles in diameter, inclosed in a thin coating of solid matter; for 200 miles are nothing when compared with the size of the earth. No doubt the form of the earth, as determined by the pendulum and arcs of the meridian, as well as by the motions of the moon, indicates original fluidity and subsequent consolidation and reduction of temperature by radiation; but whether the law of increasing temperature is uniform at still greater depths than those already attained by man, it is impossible to say.   At all events, internal fluidity is not inconsistent with the present state of the earth's surface, since earthy matter is as bad a conductor of caloric as lava, which often retains its heat at a very little depth for years after its surface is cool.   Whatever the radiation of the earth might have been in former times, certain it is that it goes on very slowly in our days; for M. Fourier has computed that the central heat is decreasing from radiation by only about the $\frac{1}{3000}$th part of a second in a century.   If so, there can be no doubt that it will ultimately be dissipated; but as far as regards animal and vegetable life, it is of very little consequence whether the center of our planet be liquid fire or ice, since its condition in either case could have no sensible effect on the climate at its surface.   The internal fire does not even impart heat

enough to melt the snow at the poles, though so much nearer to the center than any other part of the globe.

The immense extent of active volcanic fire is one of the causes of heat which must not be overlooked.

The range of the Andes from Chili to the north of Mexico, probably from Cape Horn to California, or even to New Madrid in the United States, is one vast district of igneous action, including the Caribbean Sea and the West Indian Islands on one hand; and stretching quite across the Pacific Ocean, through the Polynesian Archipelago, the New Hebrides, the Georgian and Friendly Islands, on the other. Another chain begins with the Aleutian Islands, extends to Kamtschatka, and from thence passes through the Kurile, Japanese, and Philippine Islands, to the Moluccas, whence it spreads with terrific violence through the Indian Archipelago, even to the Bay of Bengal. Volcanic action may again be followed from the entrance of the Persian Gulf to Madagascar, Bourbon, the Canaries, and Azores. Thence a continuous igneous region extends through about 1000 geographical miles to the Caspian Sea, including the Mediterranean, and extending north and south between the 35th and 40th parallels of latitude; and in central Asia a volcanic region occupies 2500 square geographical miles. The volcanic fires are developed in Iceland in tremendous force; and the antarctic land recently discovered by Sir James Ross is an igneous formation of the boldest structure, from whence a volcano in high activity rises 12,000 feet above the perpetual ice of these polar deserts, and within $19\frac{1}{2}°$ of the south pole. Throughout this vast portion of the world the subterraneous fire is often intensely active, producing such violent earthquakes and eruptions that their effects, accumulated during millions of years, may account for many of the great geological changes of igneous origin that have already taken place in the earth, and may occasion others not less remarkable, should time—that essential element in the vicissitudes of the globe—be granted, and their energy last.

Mr. Lyell, who has shown the power of existing causes with great ingenuity, estimates that on an average twenty eruptions take place annually in different parts of the

world; and many must occur or have happened, even on
the most extensive and awful scale, among people equally
incapable of estimating their effects and of recording
them. We should never have known the extent of the
fearful eruption which took place in the island of Sum-
bawa, in 1815, but for the accident of Sir Stamford Raf-
fles having been governor of Java at the time. It began
on the 5th of April, and did not entirely cease till July.
The ground was shaken through an area of 1000 miles
in circumference; the tremors were felt in Java, the
Moluccas, a great part of Celebes, Sumatra, and Borneo.
The detonations were heard in Sumatra, at the distance
of 970 geographical miles in a straight line; and at Ter-
nate, 720 miles in the opposite direction. The most
dreadful whirlwinds carried men and cattle into the air;
and with the exception of 26 persons, the whole popu-
lation of the island perished to the amount of 12,000.
Ashes were carried 300 miles to Java, in such quantities
that the darkness during the day was more profound
than ever had been witnessed in the most obscure night.
The face of the country was changed by the streams of
lava, and by the upheaving and sinking of the soil. The
town of Tomboro was submerged, and water stood to
the depth of 18 feet in places which had been dry land.
Ships grounded where they had previously anchored,
and others could hardly penetrate the mass of cinders
which floated on the surface of the sea for several miles
to the depth of two feet. A catastrophe similar to this,
though of less magnitude, took place in the island of Bali
in 1808, which was not heard of in Europe till years
afterward. The eruption of Coseguina in the Bay of
Fonseca, which began on the 19th of January, 1835, and
lasted many days, was even more dreadful and extensive
in its effects than that of Sumbawa. The ashes during
this eruption were carried by the upper current of the
atmosphere as far north as Chiassa, which is upward
of 400 leagues to the windward of that volcano. Many
volcanos supposed to be extinct have all at once burst
out with inconceivable violence. Witness Vesuvius, on
historical record; and the volcano in the island of St.
Vincent in our own days, whose crater was lined with
large trees, and which had not been active in the mem-

ory of man. Vast tracts are of volcanic origin where volcanos have ceased to exist for ages. Whence it may be inferred that in some places the subterraneous fires are in the highest state of activity, in some they are inert, and in others they appear to be extinct. Yet there are few countries that are not subject to earthquakes of greater or less intensity; the tremors are propagated like a sonorous undulation to such distances that it is impossible to say in what point they originate. In some recent instances their power must have been tremendous. In South America, so lately as 1822, an area of 100,000 square miles, which is equal in extent to the half of France, was raised several feet above its present level; a most able account of which is given in the ' Transactions of the Geological Society,' by an esteemed friend of the author, Mrs. Graham, now Mrs. Calcott, who was present during the whole time of that formidable earthquake, which recurred at short intervals for more than two months, and who possesses talents to appreciate, and had opportunities of observing, its effects under the most favorable circumstances at Valparaiso, and for miles along the coast where it was most intense. A considerable elevation of the land has again taken place along the coast of Chili, in consequence of the violent earthquake which happened on the 20th of February, 1835. In 1819, a ridge of land stretching for 50 miles across the delta of the Indus, 16 feet broad, was raised 10 feet above the plain; yet the account of this marvelous event was recently brought to Europe by Mr. Burnes. The reader is referred to Mr. Lyell's very excellent work on geology, already mentioned, for most interesting details of the phenomena and extensive effects of volcanos and earthquakes, too numerous to find a place here. It may however be mentioned, that innumerable earthquakes are from time to time shaking the solid crust of the globe, and carrying destruction to distant regions, progressively though slowly accomplishing the great work of change. These terrible engines of ruin, fitful and uncertain as they may seem, must, like all durable phenomena, have a law, which may in time be discovered by long-continued and accurate observations.

The shell of volcanic fire that girds the globe at a small depth below our feet has been attributed to different causes. By some it is supposed to originate in an ocean of incandescent matter, still existing in the central abyss of the earth. Some conceive it to be superficial, and due to chemical action, in strata at no very great depth when compared with the size of the globe. The more so, as matter on a most extensive scale is passing from old into new combinations, which, if rapidly effected, are capable of producing the most intense heat. According to others, electricity, which is so universally diffused in all its forms throughout the earth, if not the immediate cause of the volcanic phenomena, at least determines the chemical affinities that produce them. It is clear that a subject so involved in mystery must give rise to much speculation, in which every hypothesis is attended with difficulties that observation alone can remove.

But the views of Mr. Babbage and Sir John Herschel on the general cause of volcanic action, and the changes in the equilibrium of the internal heat of the globe, accord more with the laws of mechanics and radiant caloric than any that have been proposed. The theory of these distinguished philosophers, formed independently of each other, is equally consistent with observed phenomena, whether the earth be a solid crust encompassing a nucleus of liquid lava, or that there is merely a vast reservoir or stratum of melted matter at a moderate depth below the superficial crust. The author is indebted to the kindness of Mr. Lyell for the perusal of a most interesting letter from Sir John Herschel, in which he states his views on the subject.

Supposing that the globe is merely a solid crust, resting upon fluid or semi-fluid matter, whether extending to the center or not, the transfer of pressure from one part of its surface to another by the degradation of existing continents, and the formation of new ones, would be sufficient to subvert the equilibrium of heat in the interior, and occasion volcanic eruptions. For, since the internal heat of the earth is transmitted outwards by radiation, an accession of new matter on any part of the surface, like an addition of clothing, by keeping it in,

would raise the temperature of the strata below, and in the course of ages would even reduce those at a great depth to a state of fusion. Some of the substances might be converted into gases; and should the accumulation of new matter take place at the bottom of the sea, as is generally the case, this lava would be mixed with water in a state of ignition in consequence of the enormous pressure of the ocean, and of the newly superimposed matter which would prevent it from expanding into steam. Now Mr. Lyell has shown with his usual talent, that the quantity of matter carried down by rivers from the surface of the continents is comparatively trifling, and that the great transfer to the bottom of the ocean is produced at the coast line by the action of the sea; hence, says Sir John Herschel, "the greatest accumulation of local pressure is in the central area of the deep sea, while the greatest local relief takes place along the abraded coast lines. Here then should occur the chief volcanic vents." As the crust of the earth is much weaker on the coasts than elsewhere, it is more easily ruptured, and, as Mr. Babbage observes, immense rents might be produced there by its contraction in cooling down after being deprived of a portion of its original thickness. The pressure on the bottom of the ocean would force a column of lava mixed with ignited water and gas to rise through an opening thus formed, and, says Sir John Herschel, " when the column attains such a height that the ignited water can become steam, the joint specific gravity of the column is suddenly diminished, and up comes a jet of mixed steam and lava, till so much has escaped that the matter deposited at the bottom of the ocean takes a fresh bearing, when the evacuation ceases and the crack becomes sealed up."

This theory perfectly accords with the phenomena of nature, since there are very few active volcanos at a distance from the sea, and the exceptions that do occur are generally near lakes, or they are connected with volcanos on the maritime coasts. Many break out even in the bottom of the ocean, probably owing to some of the supports of the superficial crust giving way, so that the steam and lava are forced up through the fissures.

Finally, Mr. Babbage observes that " in consequence

of changes continually going on, by the destruction of forests, the filling up of seas, the wearing down of elevated lands, the heat radiated from the earth's surface varies considerably at different periods. In consequence of this variation, and also in consequence of the covering up of the bottom of the sea by the detritus of the land, the surfaces of equal temperature within the earth are continually changing their form, and exposing thick beds near the exterior to alterations of temperature. The expansion and contraction of these strata may form rents and veins, produce earthquakes, determine volcanic eruptions, elevate continents, and possibly raise mountain chains."

The numerous vents for the internal heat formed by volcanos, hot springs, and the emission of steam so frequent in volcanic regions, no doubt maintain the tranquillity of the interior fluid mass, which seems to be perfectly inert unless when put in motion by unequal pressure.

But to whatever cause the increasing heat of the earth and the subterranean fires may ultimately be referred, it is certain that, except in some local instances, they have no sensible effect on the temperature of its surface. It may therefore be concluded that the heat of the earth above the zone of uniform temperature is entirely owing to the sun.

The power of the solar rays depends much upon the manner in which they fall, as we readily perceive from the different climates on our globe. The earth is about three millions of miles nearer to the sun in winter than in summer, but the rays strike the northern hemisphere more obliquely in winter than in the other half of the year.

The observations of the north polar navigators, and those of Sir John Herschel at the Cape of Good Hope, show that the direct heating influence of the solar rays is greatest at the equator, and that it diminishes gradually as the latitude increases. At the equator the maximum is $48\frac{3}{4}°$, while in Europe it has never exceeded $29\frac{1}{2}°$.

M. Pouillet has estimated with singular ingenuity, from a series of observations made by himself, that the

whole quantity of heat which the earth receives annu-
ally from the sun is such as would be sufficient to melt
a stratum of ice covering the whole globe 46 feet deep.
Part of this heat is radiated back into space; but by far
the greater part descends into the earth during the
summer, toward the zone of uniform temperature,
whence it returns to the surface in the course of the
winter, and tempers the cold of the ground and the at-
mosphere in its passage to the ethereal regions, where
it is lost, or rather where it combines with the radiation
from the other bodies of the universe in maintaining
the temperature of space. The sun's power being
greatest between the tropics, the caloric sinks deeper
there than elsewhere, and the depth gradually dimin-
ishes toward the poles; but the heat is also transmitted
laterally from the warmer to the colder strata north and
south of the equator, and aids in tempering the severity
of the polar regions.

The mean heat of the earth above the stratum of
constant temperature is determined from that of springs;
and if the spring be on elevated ground, the temperature
is reduced by computation to what it would be at the
level of the sea, assuming that the heat of the soil
varies according to the same law as the heat of the
atmosphere, which is about 1° of Fahrenheit's ther-
mometer for every 333·7 feet. From a comparison of
the temperature of numerous springs with that of the
air, Sir David Brewster concludes that there is a par-
ticular line passing nearly through Berlin, at which the
temperature of springs and that of the atmosphere
coincide; that in approaching the arctic circle the tem-
perature of springs is always higher than that of the air,
while proceeding toward the equator it is lower.

Since the warmth of the superficial strata of the earth
decreases from the equator to the poles, there are many
places in both hemispheres where the ground has the
same mean temperature. If lines were drawn through
all those points in the upper strata of the globe which
have the same mean annual temperature, they would
be nearly parallel to the equator between the tropics,
and would become more and more irregular and sinuous
toward the poles. These are called isogeothermal lines.

A variety of local circumstances disturb their parallelism even between the tropics.

The temperature of the ground at the equator is lower on the coasts and islands than in the interior of continents; the warmest part is in the interior of Africa, but it is obviously affected by the nature of the soil, especially if it be volcanic.

Much has been done within a few years to ascertain the manner in which heat is distributed over the surface of our planet, and the variations of climate, which in a general view mean every change of the atmosphere, such as of temperature, humidity, variations of barometric pressure, purity of air, the serenity of the heavens, the effects of winds, and electric tension. Temperature depends upon the property which all bodies possess more or less, of perpetually absorbing and emitting or radiating heat. When the interchange is equal, the temperature of a body remains the same; but when the radiation exceeds the absorption, it becomes colder, and *vice versâ*. In order to determine the distribution of heat over the surface of the earth, it is necessary to find a standard by which the temperature in different latitudes may be compared. For that purpose it is requisite to ascertain by experiment the mean temperature of the day, of the month, and of the year, at as many places as possible throughout the earth. The annual average temperature may be found by adding the mean temperatures of all the months in the year, and dividing the sum by twelve. The average of ten or fifteen years will give it with tolerable accuracy; for although the temperature in any place may be subject to very great variations, yet it never deviates more than a few degrees from its mean state, which consequently offers a good standard of comparison.

If climate depended solely upon the heat of the sun, all places having the same latitude would have the same mean annual temperature. The motion of the sun in the ecliptic indeed occasions perpetual variations in the length of the day, and in the direction of the rays with regard to the earth; yet, as the cause is periodic, the mean annual temperature from the sun's motion alone must be constant in each parallel of latitude. For it is

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evident that the accumulation of heat in the long days of summer, which is but little diminished by radiation during the short nights, is balanced by the small quantity of heat received during the short days in winter, and its radiation in the long frosty and clear nights. In fact, if the globe were everywhere on a level with the surface of the sea, and of uniform substance, so as to absorb and radiate heat equally, the mean heat of the sun would be regularly distributed over its surface in zones of equal annual temperature parallel to the equator, from which it would decrease to each pole as the square of the cosine of the latitude; and its quantity would only depend upon the altitude of the sun and atmospheric currents. The distribution of heat, however, in the same parallel, is very irregular in all latitudes except between the tropics, where the isothermal lines, or the lines passing through places of equal mean annual temperature, are more nearly parallel to the equator. The causes of disturbance are very numerous; but such as have the greatest influence, according to M. de Humboldt, to whom we are indebted for the greater part of what is known on the subject, are the elevation of the continents, the distribution of land and water over the surface of the globe exposing different absorbing and radiating powers; the variations in the surface of the land, as forests, sandy deserts, verdant plains, rocks, &c.; mountain-chains covered with masses of snow, which diminish the temperature; the reverberation of the sun's rays in the valleys, which increases it; and the interchange of currents, both of air and water, which mitigates the rigor of climates; the warm currents from the equator softening the severity of the polar frosts, and the cold currents from the poles tempering the intense heat of the equatorial regions. To these may be added cultivation, though its influence extends over but a small portion of the globe, only a fourth part of the land being inhabited.

Temperature decreases with the height above the level of the sea, as well as with the latitude. The air in the higher regions of the atmosphere is much cooler than that below, because the warm air expands as it *rises, by which* its capacity for heat is increased, a great

proportion becomes latent, and less of it sensible. A portion of air at the surface of the earth whose temperature is 70° of Fahrenheit, if carried to the height of two miles and a half, would expand so much that its temperature would be reduced 50° ; and in the ethereal regions the temperature is 90° below the point of congelation.

The height at which snow lies perpetually decreases from the equator to the poles, and is higher in summer than in winter ; but it varies from many circumstances. Snow rarely falls when the cold is intense and the atmosphere dry. Extensive forests produce moisture by their evaporation ; and high table-lands, on the contrary, dry and warm the air.   In the Cordilleras of the Andes, plains of only twenty-five square leagues raise the temperature as much as 3° or 4° above what is found at the same altitude on the rapid declivity of a mountain, consequently the line of perpetual snow varies according as one or other of these causes prevails. Aspect in general has also a great influence ; yet, according to M. Jacquemont, the line of perpetual snow is much higher on the northern than on the southern side of the Himalaya mountains.   On the whole, it appears that the mean height between the tropics at which the snow lies perpetually is about 15,207 feet above the level of the sea ; whereas snow does not cover the ground continually at the level of the ocean till near the north pole. In the southern hemisphere, however, the cold is greater than in the northern.   In Sandwich Land, between the 54th and 58th degrees of latitude, perpetual snow and ice extend to the sea-beach ; and in the island of St. George's, in the 53rd degree of south latitude, which corresponds with the latitude of the central counties of England, perpetual snow descends even to the level of the ocean.   It has been shown that this excess of cold in the southern hemisphere cannot be attributed to the winter being longer than ours by 7¾ days. It is probably owing to the ice being more extensive at the south than the north pole, and to the open sea surrounding it, which permits the icebergs to descend to a lower latitude by 10° than they do in the northern hemisphere, on account of the numerous obstructions opposed to them by the islands

and continents about the north pole. Icebergs seldom float farther to the south than the Azores; whereas those that come from the south pole descend as far as the Cape of Good Hope, and occasion a continual absorption of heat in melting.

The influence of mountain-chains does not wholly depend upon the line of perpetual congelation. They attract and condense the vapors floating in the air, and send them down in torrents of rain. They radiate heat into the atmosphere at a lower elevation, and increase the temperature of the valleys by the reflection of the sun's rays, and by the shelter they afford against prevailing winds. But on the contrary, one of the most general and powerful causes of cold arising from the vicinity of mountains, is the freezing currents of wind which rush from their lofty peaks along the rapid declivities, chilling the surrounding valleys: such is the cutting north wind called the bise in Switzerland.

Next to elevation, the difference in the radiating and absorbing powers of the sea and land has the greatest influence in disturbing the regular distribution of heat. The extent of the dry land is not above the fourth part of that of the ocean; so that the general temperature of the atmosphere, regarded as the result of the partial temperatures of the whole surface of the globe, is most powerfully modified by the sea. Besides, the ocean acts more uniformly on the atmosphere than the diversified surface of the solid mass does, both by the equality of its curvature and its homogeneity. In opaque substances the accumulation of heat is confined to the stratum nearest the surface. The seas become less heated at their surface than the land, because the solar rays, before being extinguished, penetrate the transparent liquid to a greater depth and in greater numbers than in the opaque masses. On the other hand, water has a considerable radiating power, which, together with evaporation, would reduce the surface of the ocean to a very low temperature, if the cold particles did not sink to the bottom on account of their superior density. The seas preserve a considerable portion of the heat they receive in summer, and from their saltness do not freeze so soon as fresh water. So that in consequence

of all these circumstances, the ocean is not subject to
such variations of heat as the land; and by imparting
its temperature to the winds, it diminishes the rigor of
climate on the coasts and in the islands, which are
never subject to such extremes of heat and cold as are
experienced in the interior of continents, though they
are liable to fogs and rain from the evaporation of the
adjacent seas.   On each side of the equator to the 48th
degree of latitude, the surface of the ocean is in gene-
ral warmer than the air above it.   The mean of the
difference of the temperature at noon and midnight is
about $1°\cdot37$, the greatest deviation never exceeding from
$0°\cdot36$ to $2°\cdot16$, which is much cooler than the air over
the land.

On land the temperature depends upon the nature
of the soil and its products, its habitual moisture or dry-
ness.   From the eastern extremity of the Sahara
desert quite across Africa, the soil is almost entirely
barren sand; and the Sahara desert itself, without in-
cluding Dafour or Dongola, extends over an area of
194,000 square leagues, equal to twice the area of the
Mediterranean Sea, and raises the temperature of the
air by radiation from $90°$ to $100°$, which must have a
most extensive influence.   On the contrary, vegetation
cools the air by evaporation and the apparent radiation
of cold from the leaves of plants, because they absorb
more caloric than they give out.   The graminiferous
plains of South America cover an extent ten times
greater than France, occupying no less than about
50,000 square leagues, which is more than the whole
chain of the Andes, and all the scattered mountain-
groups of Brazil.   These, together with the plains of
North America and the steppes of Europe and Asia,
must have an extensive cooling effect on the atmosphere
if it be considered that in calm and serene nights they
cause the thermometer to descend $12°$ or $14°$, and that
in the meadows and heaths in England the absorption
of heat by the grass is sufficient to cause the tempera-
ture to sink to the point of congelation during the night
for ten months in the year.   Forests cool the air also
by shading the ground from the rays of the sun, and by
evaporation from the boughs.   Hales found that the

Eléctricity may be called into activity by mechanical power, by chemical action, by heat, and by magnetic influence. We are totally ignorant why it is roused from its neutral state by such means, or of the manner of its existence in bodies, whether it be a material agent, vibrations of ether, or merely a property of matter. Various circumstances render it more than probable that, like light and heat, it is a modification or vibration of that subtile ethereal medium which in a highly elastic state pervades all space, and which is capable of moving with various degrees of facility through the pores even of the densest substances. As experience shows that bodies in one electric state attract, and in another repel each other, the hypothesis of two fluids has been adopted by many philosophers; but probably the mutual attraction and repulsion of bodies arise from the redundancy and defect of their electricities, though all the electrical phenomena can be explained on either hypothesis. Bodies having a redundancy of the electric fluid are said to be positively electric, and those in defect negatively. As each kind of electricity has its peculiar properties, the science may be divided into four branches, of which the following notice is intended to convey some idea.

Substances in a neutral state neither attract nor repel. There is a numerous class called electrics, in which the electric equilibrium is destroyed by friction; then the positive and negative electricities are called into action or separated; the positive is impelled in one direction, and the negative in another; or more correctly, the electricity is impelled in one direction at the expense of the other where there is a deficiency of it. Electricities of the same kind repel, whereas those of different kinds attract each other. The attractive power is exactly equal to the repulsive power at equal distances, and when not opposed, they coalesce with great rapidity and violence; producing the electric flash, explosion, and shock: then equilibrium is restored, and the electricity remains latent till again called forth by a new exciting cause. One kind of electricity cannot be evolved without the evolution of an equal quantity of the opposite kind. Thus when a

glass rod is rubbed with a piece of silk, as much positive electricity is elicited in the glass as there is negative in the silk; or in other words there is a redundancy in the glass and a proportional deficiency in the silk. The kind of electricity depends more upon the mechanical condition than on the nature of the surface: for when two plates of glass, one polished and the other rough, are rubbed against each other, the polished surface acquires positive and the rough negative electricity; that is, the one gains and the other loses. The manner in which friction is performed also alters the kind of electricity. Equal lengths of black and white riband applied longitudinally to one another, and drawn between the finger and thumb, so as to rub their surfaces together, become electric. When separated, the white riband is found to have acquired positive electricity, and the black has lost it, or become negative: but if the whole length of the black riband be drawn across the breadth of the white, the black will be positively and the white negatively electric when separate. Electricity may be transferred from one body to another in the same manner as heat is communicated, and like it too, the body loses by the transmission. Although no substance is altogether impervious to the electric fluid, nor is there any that does not oppose some resistance to its passage, yet it moves with much more facility through a certain class of substances called conductors, such as metals, water, the human body, &c., than through atmospheric air, glass, silk, &c., which are therefore called non-conductors. The conducting power is affected both by temperature and moisture.

Bodies surrounded with non-conductors are said to be insulated, because, when charged, the electricity cannot escape. When that is not the case, the electricity is conveyed to the earth, which is formed of conducting matter; consequently it is impossible to accumulate electricity in a conducting substance that is not insulated. There are a great many substances called non-electrics, in which electricity is not sensibly developed by friction, unless they be insulated, probably because it is carried off by their conducting power as soon as elicited. Metals, for example, which are said to be

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St. George's Bay, Newfoundland, latitude 48°: and lastly, the line of 32°, the freezing point of water, passes between Ulea in Lapland, latitude 66°, and Table Bay, on the coast of Labrador, latitude 54°.

Thus it appears that the isothermal lines, which are nearly parallel to the equator for about 22°, afterward deviate more and more. From the observations of Sir Charles Giesecke in Greenland, of Captain Scoresby in the Arctic Seas, and also from those of Sir Edward Parry and Sir John Franklin, it is found that the isothermal lines of Europe and America entirely separate in the high latitudes, and surround two poles of maximum cold, one in America and the other in the north of Asia, neither of which coincides with the pole of the earth's rotation. These poles are both situate in about the 80th parallel of north latitude. The transatlantic pole is in the 100th degree of west longitude, about 5° to the north of Sir Graham Moore's Bay, in the Polar Seas; and the Asiatic pole is in the 95th degree of east longitude, a little to the north of the Bay of Taimura, near the North-east Cape. According to the estimation of Sir David Brewster, from the observations of M. de Humboldt and Captains Parry and Scoresby, the mean annual temperature of the Asiatic pole is nearly 1° of Fahrenheit's thermometer, and that of the transatlantic pole about $3\frac{1}{2}$° below zero, whereas he supposes the mean annual temperature of the pole of rotation to be 4° or 5°. It is believed that two corresponding poles of maximum cold exist in the southern hemisphere, though observations are wanting to trace the course of the southern isothermal lines with the same accuracy as the northern.

The isothermal lines, or such as pass through places where the mean annual temperature of the air is the same, do not always coincide with the isogeothermal lines, which are those passing through places where the mean temperature of the ground is the same. Sir David Brewster, in discussing this subject, finds that the isogeothermal lines are always parallel to the isothermal lines; consequently the same general formula will serve to determine both, since the difference is a constant quantity obtained by observation, and depend-

ing upon the distance of the place from the neutral iso-
thermal line.   These results are confirmed by the ob-
servations of M. Kupffer of Kasan during his excursions
to the north, which show that the European and the
American portions of the isogeothermal line of 32° of
Fahrenheit actually separate, and go round the two
poles of maximum cold.   This traveler remarked, also,
that the temperature both of the air and of the soil de-
creases most rapidly toward the 45th degree of latitude.

It is evident that places may have the same mean an-
nual temperature, and yet differ materially in climate.
In one, the winters may be mild, and the summers cool;
whereas another may experience the extremes of heat
and cold.   Lines passing through places having the
same mean summer or winter temperature, are neither
parallel to the isothermal, the geothermal lines, nor to one
another, and they differ still more from the parallels of
latitude.   In Europe, the latitude of two places which
have the same annual heat never differs more than 8° or
9°; whereas the difference in the latitude of those having
the same mean winter temperature is sometimes as
much as 18° or 19°.   At Kasan in the interior of Rus-
sia, in latitude 55°·48, nearly the same with that of
Edinburgh, the mean annual temperature is about 37°·6;
at Edinburgh it is 47°·84.   At Kasan, the mean sum-
mer temperature is 64°·84, and that of winter 2°·12;
whereas at Edinburgh the mean summer temperature
is 58°·28, and that of winter 38°·66.   Whence it ap-
pears that the difference of winter temperature is much
greater than that of summer.   At Quebec, the sum-
mers are as warm as those in Paris, and grapes some-
times ripen in the open air: whereas the winters are
as severe as in Petersburgh; the snow lies five feet
deep for several months, wheel carriages cannot be used,
the ice is too hard for skating, traveling is performed in
sledges, and frequently on the ice of the river St. Law-
rence.   The cold at Melville Island on the 15th of Jan-
uary, 1820, according to Sir Edward Parry, was 55°
below the zero of Fahrenheit's thermometer, only 3°
above the temperature of the ethereal regions, yet the
summer heat in these high latitudes is insupportable.

Observations tend to prove that all the climates of the

able, and that their vicissitudes are only
cillations of more or less extent, which van-
an annual temperature of a sufficient num-
This constancy of the mean annual temper-
different places on the surface of the globe
he same quantity of heat, which is annually
the earth, is annually radiated into space.
a variety of causes may disturb the climate
place ; cultivation may make it warmer ; but it is
expense of some other place, which becomes
in the same proportion. There may be a suc-
n of cold summ.... .... winters, but in some
country the contrary ta es place to effect the
ensation ; wind, rain, snow fog, and the other me-
phenomena, are the minis. rs employed to accom-
he changes. The distribution of heat may vary
variety of circumstances ; but the absolute quan-
and gained by the whole earth in the course of
is invariably the same.

Section XXVII.

Influence of Temperature on Vegetation—Vegetation varies with the Lati
tude and Height above the Sea—Geographical Distribution of Land
Plants—Distribution of Marine Plants—Corallines, Shell-fish, Reptiles,
Insects, Birds, and Quadrupeds—Varieties of Mankind, yet Identity of
Species.

THE gradual decrease of temperature in the air and in
the earth, from the equator to the poles, is clearly indi-
cated by its influence on vegetation. In the valleys of
the torrid zone, where the mean annual temperature is
very high, and where there is abundance of light and
moisture, nature adorns the soil with all the luxuriance
of perpetual summer. The palm, the bombax ceiba,
and a variety of magnificent trees, tower to the height
of 150 or 200 feet above the banana, the bamboo, the
arborescent fern, and numberless other tropical produc-
tions, so interlaced by creeping and parasitical plants as
often to present an impenetrable barrier. But the
richness of vegetation gradually diminishes with the tem-
perature · the splendor of the tropical forest is succeeded

by the regions of the olive and vine; these again yield to the verdant meadows of more temperate climes; then follow the birch and the pine, which probably owe their existence in very high latitudes more to the warmth of the soil than to that of the air. But even these enduring plants become dwarfish stunted shrubs, till a verdant carpet of mosses and lichens, enameled with flowers, exhibits the last sign of vegetable life during the short but fervent summers at the polar regions. Such is the effect of cold and diminished light on the vegetable kingdom, that the number of species growing under the line, and in the northern latitudes of 45° and 68°, are in the proportion of the numbers 12, 4, and 1. Notwithstanding the remarkable difference between a tropical and polar Flora, light and moisture seem to be almost the only requisites for vegetation, since neither heat, cold, nor even comparative darkness, absolutely destroy the fertility of nature. In salt plains and sandy deserts alone, hopeless barrenness prevails. Plants grow on the borders of hot springs—they form the oasis wherever moisture exists, among the burning sands of Africa—they are found in caverns almost void of light, though generally blanched and feeble. The ocean teems with vegetation. The snow itself not only produces a red alga, discovered by Saussure in the frozen declivities of the Alps, found in abundance by the author crossing the Col de Bonhomme from Savoy to Piedmont, and by the polar navigators in the Arctic regions, but it affords shelter to the productions of those inhospitable climes against the piercing winds that sweep over fields of everlasting ice. Those interesting mariners narrate, that under this cold defence plants spring up, dissolve the snow a few inches round, and the part above being again quickly frozen into a transparent sheet of ice, admits the sun's rays, which warm and cherish the plants in this natural hot-house, till the returning summer renders such protection unnecessary.

The chemical action of light is, however, absolutely requisite for the growth of plants which derive their principal nourishment from the atmosphere. They consume carbonic acid gas, vapor, nitrogen, and the ammonia it contains; but it is the chemical agency of light

pears that the resistance of the air to the passage of the
electric fluid is proportional to the square of its density,
but that the action of electricity on distant bodies by in-
duction is quite independent of atmospheric pressure,
and is the same in vacuo as in air.

The power of retaining electricity depends also upon
the shape of the body. It is most easily retained by a
sphere, next to that by a spheroid, but it readily escapes
from a point; and a pointed object receives it with
most facility. It appears from analysis, that electricity,
when in equilibrio, spreads itself in a thin stratum over
the surface of a sphere, in consequence of the repulsion
of its particles, which force is directed from the center
to the surface. In an oblong spheroid, the intensity or
thickness of the stratum of electricity at the extremities
of the two axes is exactly in the proportion of the axes
themselves; hence, when the ellipsoid is much elon-
gated, the electricity becomes very feeble at the equator,
and powerful at the poles. A still greater difference in
the intensities takes place in bodies of cylindrical or
prismatic form, and the more so in proportion as their
length exceeds their breadth; therefore the electrical
intensity is very powerful at a point where nearly the
whole electricity in the body is concentrated. Not-
withstanding these analytical results, it is doubted
whether the disposition of electrified bodies to discharge
their electricity from points or edges may not arise from
the superior attractive force generated by induction in
external bodies, rather than from an original concentra-
tion of the electric fluid in these parts.

A perfect conductor is not mechanically affected by
the passage of electricity, if it be of sufficient size to
carry off the whole; but it is shivered to pieces in an
instant if it be too small to carry off the charge: this
also happens to a bad conductor. In that case the
physical change is generally a separation of the particles,
though it may occasionally be attributed to chemical
action, or expansion from the heat evolved during the
passage of the fluid; but all these effects are in propor-
tion to the obstacles opposed to the freedom of its
course. The heat produced by the electric shock is
intense, fusing metals, and even volatilizing substances,

though it is only accompanied by light when the fluid is obstructed in its passage.

Electrical light, when analyzed by the prism, presents very different appearances to the solar light. Frauenhofer found that instead of the fixed dark lines of the solar spectrum, the spectrum of an electric spark was crossed by very numerous bright lines; and Professor Wheatstone has observed that the number and position of the lines differ with the metal from which the spark is taken. According to M. Biot, electrical light arises from the condensation of the air during the rapid motion of the electricity, and varies both in intensity and color with the density of the atmosphere. When the air is dense, it is white and brilliant; whereas in rarefied air it is diffuse and of a reddish color. The experiments of Sir Humphry Davy, however, seem to be at variance with this opinion. He passed the electric spark through a vacuum over mercury, which, from green, became successively sea-green, blue, and purple, on admitting different quantities of air. When the vacuum was made over a fusible alloy of tin and bismuth, the spark was yellowish and extremely pale. Sir Humphry thence concluded, that electrical light principally depends upon some properties belonging to the ponderable matter through which it passes, and that space is capable of exhibiting luminous appearances, though it does not contain an appreciable quantity of this matter. He thought it not improbable that the superficial particles of bodies which form vapor, when detached by the repulsive power of heat, might be equally separated by the electric forces, and produce luminous appearances in vacuo, by the destruction of their opposite electric states. Professor Wheatstone has been led to conclude that electrical light results from the volatilization and ignition of the ponderable matter of the conductor itself.

Pressure is a source of electricity which M. Becquerel has found to be common to all bodies; but it is necessary to insulate them to prevent its escape. When two substances of any kind whatever are insulated and pressed together, they assume different electric states, but they only show contrary electricities when one of them is a

any one part of a cloud is extremely small. The inten-
sity of the flash arises from the very great extent of
surface occupied by the electricity; so that clouds may
be compared to enormous Leyden jars thinly coated
with the electric fluid, which only acquires its intensity
by its instantaneous condensation. The rapid and irreg-
ular motions of thunder clouds are, in all probability,
more owing to strong electrical attractions and repul-
sions among themselves than to currents of air, though
both are no doubt concerned in these hostile move-
ments.

Since the air is a non-conductor, it does not convey
the electricity from the clouds to the earth, but it ac-
quires from them an opposite electricity, and when the
tension is very great the force of the electricity becomes
irresistible, and an interchange takes place between the
clouds and the earth; but so rapid is the motion of light-
ning, that it is difficult to ascertain when it goes from the
clouds to the earth, or shoots upward from the earth
to the clouds, though there can be no doubt that it does
both. In a storm which occurred at Manchester, in the
month of June, 1835, the electric fluid was observed to
issue from various points of a road, attended by explo-
sions as if pistols had been fired out of the ground. A
man appears to have been killed by one of these explo-
sions taking place under his right foot. M. Gay-Lussac
has ascertained that a flash of lightning sometimes darts
more than three miles at once in a straight line.

A person may be killed by lightning, although the
explosion takes place at the distance of twenty miles,
by what is called the back stroke. Suppose that the
two extremities of a cloud highly charged with electri-
city hang down toward the earth: they will repel the
electricity from the earth's surface, if it be of the same
kind with their own, and will attract the other kind;
and if a discharge should suddenly take place at one
end of the cloud, the equilibrium will instantly be re-
stored by a flash at that point of the earth which is un-
der the other. Though the back stroke is often suffi-
ciently powerful to destroy life, it is never so terrible in
its effects as the direct shock, which is frequently of
inconceivable intensity. Instances have occurred in

which large masses of iron and stone, and even many feet of a stone wall, have been conveyed to a considerable distance by a stroke of lightning. Rocks and the tops of mountains often bear the marks of fusion from its action; and occasionally vitreous tubes, descending many feet into banks of sand, mark the path of the electric fluid. Some years ago, Dr. Fiedler exhibited several of these fulgorites in London, of considerable length, which had been dug out of the sandy plains of Silesia and Eastern Prussia. One found at Paderborn was forty feet long. Their ramifications generally terminate in pools or springs of water below the sand, which are supposed to determine the course of the electric fluid. No doubt the soil and substrata must influence its direction, since it is found by experience that places which have been struck by lightning are often struck again. A school-house in Lammermuir, East Lothian, has been struck three different times.

The atmosphere, at all times positively electric, becomes intensely so on the approach of rain, snow, wind, hail, or sleet; but it afterward varies, and the transitions are very rapid on the approach of a thunder-storm. An isolated conductor then gives out such quantities of sparks that it is dangerous to approach it, as was fatally experienced by Professor Richman, at Petersburg, who was struck dead by a globe of fire from the extremity of a conductor, while making experiments on atmospheric electricity. There is no instance on record of an electric cloud of high tension being dispelled by a conducting rod silently withdrawing the electric fluid; yet it may mitigate the stroke, or render it harmless if it should come. Copper conductors afford the best protection against lightning, especially if they expose a broad surface, since the electric fluid is conveyed along the exterior of bodies. Conductors do not attract the electric fluid from the clouds; their object is to carry it off in case of a stroke, and therefore they ought to project very little, if at all, above the building.

When the air is highly rarefied by heat, its coercive power is diminished so that the electric fluid escapes from the clouds, and never can be accumulated beyond

a certain limit; whence those lambent diffuse flashes of lightning without thunder so frequent in warm summer evenings.

The velocity of electricity is so great, that the most rapid motion which can be produced by art appears to be actual rest when compared with it. A wheel revolving with celerity sufficient to render its spokes invisible, when illuminated by a flash of lightning, is seen for an instant with all its spokes distinct, as if it were in a state of absolute repose; because, however rapid the rotation may be, the light has come and already ceased before the wheel has had time to turn through a sensible space. This beautiful experiment is due to Professor Wheatstone, as well as the following variation of it, which is not less striking: Since a sunbeam consists of a mixture of blue, yellow, and red light, if a circular piece of pasteboard be divided into three sectors, one of which is painted blue, another yellow, and a third red, it will appear to be white when revolving quickly, because of the rapidity with which the impressions of the colors succeed each other on the retina. But the instant it is illuminated by an electric spark, it seems to stand still, and each color is as distinct as if it were at rest. This transcendent speed of the electric fluid has been ingeniously measured by Professor Wheatstone; and although his experiments are not far enough advanced to enable him to state its absolute celerity, he has ascertained that it much surpasses the velocity of light.

In the horizontal diameter of a small disc fixed on the wall of a darkened room are disposed six small brass balls, well insulated from each other. An insulated copper wire half a mile long is disjoined in its middle, and also near its two extremities; the six ends thus obtained are connected with the six balls on the disc. When an electric discharge is sent through the wire by connecting its two extremities, one with the positive, and the other with the negative coating of a Leyden jar, three sparks are seen on the disc, apparently at the same instant. At the distance of about ten feet, a small revolving mirror is placed so as to reflect these three sparks during its revolution. From the extreme velocity of the electricity, it is clear, that if the three sparks be

simultaneous, they will be reflected, and will vanish before the mirror has sensibly changed its position, however rapid its rotation may be, and they will be seen in a straight line.   But if the three sparks be not simultaneously transmitted to the disc—if one, for example, be later than the other two—the mirror will have time to revolve through an indefinitely small arc in the interval between the reflection of the two sparks and that of the single one.   However, the only indication of this small motion of the mirror will be, that the single spark will not be reflected in the same straight line with the other two, but a little above or below it, for the reflection of all three will still be apparently simultaneous, the time intervening being much too short to be appreciated.

Since the number of revolutions which the revolving mirror makes in a second are known, and the angular deviation of the reflection of the single spark from the reflection of the other two can be measured, the time elapsed between their consecutive reflections can be ascertained.   And as the length of that part of the wire through which the electricity has passed is given, its velocity may be found.

Since the number of pulses in a second requisite to produce a musical note of any pitch is known, the number of revolutions accomplished by the mirror in a given time may be determined from the musical note produced by a tooth or peg in its axis of rotation striking against a card, or from the notes of a siren attached to the axis. It was thus that Professor Wheatstone found the mirror which he employed in his experiments to make 800 revolutions in a second; and as the angular velocity of the reflected image in a revolving mirror is double that of the mirror itself, an angular deviation of one degree in the appearance of the two sparks would indicate an interval of the 576,000th of a second; the deviation of half a degree would, therefore, indicate more than the millionth of a second.   The use of sound as a measure of velocity is a happy illustration of the connection of the physical sciences.

When the atmosphere is highly charged with electricity, it not unfrequently happens that electric light in the form of a star is seen on the topmast and yard-arms

of ships. In 1831 the French officers at Algiers were surprised to see brushes of light on the heads of their comrades, and at the points of their fingers, when they held up their hands. This phenomenon was well known to the ancients, who reckoned it a lucky omen.

Many substances in decaying emit light, which is attributed to electricity, such as fish and rotten wood. Oyster shells, and a variety of minerals, become phosphorescent at certain temperatures, when exposed to electric shocks or friction: indeed most of the causes which disturb molecular equilibrium give rise to phosphoric phenomena. The minerals possessing this property are generally colored or imperfectly transparent; and though the color of this light varies in different substances, it has no fixed relation to the color of the mineral. An intense heat entirely destroys this property, and the phosphorescent light developed by heat has no connection with light produced by friction, for Sir David Brewster observed that bodies deprived of the faculty of emitting the one are still capable of giving out the other. Among the bodies which generally become phosphorescent when exposed to heat, there are some specimens which do not possess this property, wherefore phosphorescence cannot be regarded as an essential character of the minerals possessing it. Sulphuret of calcium, known as Canton's phosphorus, and the sulphuret of barium, or Bologna stone, possess the phosphorescent property in an eminent degree, and M. Edmond Becquerel has shown that on these substances a very remarkable phosphorescent effect is produced by the action of the different rays of the solar spectrum. In former times Beccaria stated that the violet ray was the most energetic, and the red ray the least so, in exciting phosphoric light. M. Becquerel has shown that two luminous bands separated by a dark one are excited by the solar spectrum on paper covered with a solution of gum-arabic and strewed with powdered sulphuret of calcium. One of the luminous bands occupies the space under the least refrangible violet rays, and the other that beyond the lavender rays, so that the dark band lies on the part under the extreme violet and lavender rays. When the action of the spectral light is continued, the whole surface beyond

the least refrangible violet shines, the luminous bands
already mentioned brightest, but all the space from the
least refrangible violet to the extreme red remains dark.
If the surface prepared with either the sulphuret of cal-
cium or the Bologna stone be exposed to the sun's light
for a short time it becomes luminous all over, but when
in this state a solar spectrum is thrown upon it, the
whole remains luminous except the part from the least
refrangible violet to the extreme red, on which space
the light is extinguished; and when the temperature of
this surface is raised by a lamp, the bright parts become
more luminous and the dark parts remain dark.   Glass
stained by the protoxide of copper, which transmits only
the red and orange rays together with the chemical rays
that accompany them, has the same effect with the less
refrangible part of the spectrum; hence there can be no
doubt that the most refrangible and obscure rays of the
spectrum excite phosphorescence, while all the less re-
frangible rays of light and heat extinguish it.   It appears
from the experiments of MM. Biot and Becquerel that
electrical disturbance produces these phosphorescent
effects.   There is thus a mysterious connection between
the most refrangible rays and electricity, which the ex-
periments of M. E. Becquerel confirm, showing that
electricity is developed during chemical action by the
violet rays, that it is very feebly developed by the blue
and indigo, but that none is excited by the less refrangi-
ble part of the spectrum.

   Paper prepared with the sulphuret of barium when
under the solar spectrum shows only one space of max-
imum luminous intensity, and the destroying rays are
the same as in sulphuret of calcium.

   Thus the obscure rays beyond the extreme violet
possess the property of producing light, while the lumi-
nous rays have the power of extinguishing it.

   The phosphoric spectrum has inactive lines which
coincide with those in the luminous and chemical spec-
tra at least as far as it extends, but in order to be seen,
the spectrum must be received for a few seconds upon
the prepared surface through an aperture in a dark
room, then the aperture must be closed, and the tem-
perature of the surface raised two or three hundred

copper plate belonging to the second pair, and transferred
to the second zinc plate, with which it is connected.
The second plate of zinc possessing equal powers, and
acting in conformity with the first, having thus acquired
a larger portion of electricity than its natural share,
communicates a larger quantity to the fluid in the second
cell.   This increased quantity is again transferred to
the next pair of plates ; and thus every succeeding al-
ternation is productive of a further increase in the
quantity of the electricity developed.   This action,
however, would stop unless a vent were given to the
accumulated electricity, by establishing a communication
between the positive and negative poles of the battery,
by means of wires attached to the extreme plate at each
end.   When the wires are brought into contact, the
Voltaic circuit is completed, the electricities meet and
neutralize each other, producing the shock and other
electrical phenomena ; and then the electric current
continues to flow uninterruptedly in the circuit, as long
as the chemical action lasts.   The stream of positive
electricity flows from the zinc to the copper.   The
construction and power of the Voltaic battery has been
much improved of late years, but the most valuable
recent improvement is the constant battery of Professor
Daniell.   In all batteries of the ordinary construction,
the power, however energetic at first, rapidly diminishes,
and ultimately becomes very feeble.   Professor Daniell
found that this diminution of power is occasioned by the
adhesion of the evolved hydrogen to the surface of the
copper, and to the precipitation of the sulphate formed
by the action of the acid on the zinc.   He prevents the
latter by interposing between the copper and the zinc,
in the cell containing the liquid, a membrane which,
without impeding the electric current, prevents the
transfer of the salt; and the former, by placing between
the copper and the membrane solution of sulphate of
copper, which being reduced by the hydrogen prevents
the adhesion of this gas to the metallic surface.   Each
element of the battery consists of a hollow cylinder of
copper, in the axis of which is placed a cylindrical rod of
zinc ; between the zinc and the copper a membranous
bag is placed, which divides the cell into two portions,

the inner of which is filled with dilute acid, and the one nearer the copper is supplied with crystals of the sulphate of that metal. The battery consists of several of these elementary cells connected together by metallic wires, the zinc rod of one with the copper cylinder of that next to it. The zinc rods are amalgamated, so that local action, which in ordinary cases is so destructive of the zinc, does not take place, and no chemical action is manifested unless the circuit be completed. The rods are easily detached, and others substituted for them when worn out. This battery, which possesses considerable power, and is constant in its effects for a very long period of time, is greatly superior to all former arrangements, either as an instrument of research, or for exhibiting the ordinary phenomena of Voltaic electricity.

A battery charged with water alone, instead of acid, is very constant in its action, but the quantity of electricity it developes is comparatively very small. Mr. Cross of Broomfield in Somersetshire, has kept a battery of this kind in full force during twelve months. M. Becquerel had invented an instrument for comparing the intensities of the different kinds of electricity by means of weights; but as it is impossible to make the comparison with Voltaic electricity produced by the ordinary batteries, on account of the perpetual variation to which the intensity of the current is liable, he has constructed a battery which affords a continued stream of electricity of uniform power, but it is also of very feeble force. The current is produced by the chemical combination of an acid with an alkali.

Metallic contact is not necessary for the production of Voltaic electricity, which is entirely due to chemical action. The intensity of the Voltaic electricity is in proportion to the intensity of the affinities concerned in its production, and the quantity produced is in proportion to the quantity of matter which has been chemically active during its evolution. Dr. Faraday considers this definite production to be one of the strongest proofs that the electricity is of chemical origin.

Galvanic or Voltaic, like common electricity, may either be considered to consist of two fluids passing in opposite directions through the circuit, or, if the hypoth-

line, and lastly a violet line. The spark taken from zinc, cadmium, tin, bismuth, and lead in the melted state, gives similar results; but the number, position, and color of the lines vary so much in each case, and the appearances are so different, that the metals may be easily distinguished from each other by this mode of investigation. It appears, moreover, that the light does not arise from the combustion of the metal; for the Voltaic spark taken from mercury successively in the vacuum of an air-pump, in the Torricellian vacuum, and in carbonic acid gas, is precisely the same as when the experiment is performed in the air or in oxygen gas. Notwithstanding the difference between electric and solar light, M. Arago is inclined to attribute the intense light and heat of the sun to electrical action.

Voltaic electricity is a powerful agent in chemical analysis. When transmitted through conducting fluids it separates them into their constituent parts, which it conveys in an invisisible state through a considerable space or quantity of liquid to the poles, where they come into evidence. Numerous instances might be given, but the decomposition of water is perhaps the most simple and elegant. Suppose a glass tube filled with water and corked at both ends; if one of the wires of an active Voltaic battery be made to pass through one cork and the other through the other cork, into the water, so that the extremities of the two wires shall be opposite and about a quarter of an inch asunder, chemical action will immediately take place, and gas will continue to rise from the extremities of both wires till the water has vanished. If an electric spark be then sent through the tube, the water will reappear. By arranging the experiment so as to have the gas given out by each wire separately, it is found that water consists of two volumes of hydrogen and one of oxygen. The hydrogen is given out at the positive wire of the battery, and the oxygen at the negative. The oxides are also decomposed; the oxygen appears at the positive pole, and the metal at the negative. The decomposition of the alkalies and earths by Sir Humphry Davy formed a remarkable era in the history of Science. Soda, potass, lime, magnesia, and other substances heretofore

considered to be simple bodies incapable of decomposi-
tion, were resolved by electric agency into their constit-
uent parts, and proved to be metallic oxides, by that
illustrious philosopher. All chemical changes produced
by the electric fluid are accomplished on the same prin-
ciple ; and it appears that in general, combustible sub-
stances, metals, and alkalies go to the negative wire,
while acids and oxygen are evolved at the positive.
The transfer of these substances to the poles is not the
least wonderful effect of the Voltaic battery. Though
the poles be at a considerable distance from one another,
nay, even in separate vessels, if a communication be
only established by a quantity of wet thread, as the de-
composition proceeds the component parts pass through
the thread in an invisible state, and arrange themselves
at their respective poles. According to Dr. Faraday,
electro-chemical decomposition is simply a case of the
preponderance of one set of chemical affinities more
powerful in their nature over another set which are less
powerful. The great efficacy of Voltaic electricity in
chemical decomposition arises from the continuance of
its action ; and its agency appears to be most exerted
on fluids and substances which, by conveying the elec-
tricity partially and imperfectly, impede its progress.
But it is now proved to be as efficacious in the compo-
sition as in the decomposition or analysis of bodies.

It had been observed that when metallic solutions are
subjected to galvanic action, a deposition of metal, some-
times in the form of minute crystals, takes place on the
negative wire. By extending this principle, and em-
ploying a very feeble Voltaic action, M. Becquerel has
succeeded in forming crystals of a great proportion of
the mineral substances, precisely similar to those pro-
duced by nature. The electric state of metallic veins
makes it possible that many natural crystals may have
taken their form from the action of electricity bringing
their ultimate particles, when in solution, within the
narrow sphere of molecular attraction already mentioned
as the great agent in the formation of solids. Both light
and motion favor crystalization. Crystals which form
in different liquids are generally more abundant on the
side of the jar exposed to the light ; and it is well known

points have been ascertained in which that curve cuts
the equator; yet Captain Duperry, who crossed it re-
peatedly, affirms, from his own observations combined
with those of M. Jules de Bosville and of Colonel
Sabine, that it crosses the terrestrial equator in two
points only, and those diametrically opposite one to the
other, and not far from the meridian of Paris.   One of
these nodes he places in the Atlantic, the other in the
Pacific ocean.   He finds that the magnetic equator
deviates but little from the terrestrial equator in that
part of the Pacific where there are only a few scattered
islands (b), that as the islands become more frequent
the deviation increases, and arrives at a maximum both
to the north and south in traversing the African and
American continents; and that the symmetry of the
northern and southern segments of this curve is much
greater than was imagined.

The intensity of the magnetic force is different in dif-
ferent parts of the earth.   If a magnetic needle, freely
suspended so as to move horizontally, and at rest in a
magnetic meridian, be drawn any number of degrees
from that position, it will make a certain number of os-
cillations before it resumes its state of rest.   The inten-
sity of the magnetic force is determined from these os-
cillations, in the same manner that the intensity of the
gravitating and electrical forces is known from the vibra-
tions of the pendulum and the balance of torsion (c):
and in all these cases it is proportional to the squares of
the number of oscillations performed in a given time,
consequently a comparison of the number of vibrations
accomplished by the same needle during the same time
in different parts of the earth's surface will determine
the variations in the magnetic action.   By this method
it was discovered that the intensity of the magnetic force
increases from the equator toward the poles; but the
foci of the greatest total intensity of the magnetic force
seem neither to coincide with the magnetic nor rotatory
poles of the earth (d).   One of these foci, according to
Colonel Sabine's magnetic chart, is situate about the 47°
south latitude and 140° east longitude, while another of
less energy is in 60° south latitude and 235° east longi-
tude.   The point of least total magnetic intensity on the

whole globe is by the same chart about the 25° south latitude and 12° west longitude. In the northern hemisphere the foci of maximum intensity are in lat. 54° 32′ N., long. 261° 27′ E., and lat. 71° 20′ N., long. 119° 57′ E., according to M. Gauss's calculations. The magnetic intensity appears to be doubled in the ascent from the equator to Baffin's bay.

Such are the principal phenomena of terrestrial magnetism, but it is subject to secular, periodical, and transient disturbances still imperfectly known. In the northern hemisphere, the poles, the lines of equal and no variation, the equator, and in short the whole system is gradually moving toward the east, so that the relations observed in Europe two centuries ago have now reached the limits between Europe and Asia, while other parts of the system have moved gradually over to us from the west. In the southern hemisphere the secular motion of the poles and of the whole system is in a contrary direction. The cause of these secular disturbances is altogether unknown.

The horizontal needle or compass at any one place is also subject to periodic and transient perturbations. Great disturbances occur on the same day, or nearly on the same day, in different years, from causes unknown.

There are also disturbances which, according to the observations of M. Kreil, in Milan, depend on the declination of the moon and her distance from the earth ; others of shorter duration seem to be intimately connected with the motion of the sun in regard to the magnetic meridian of the place of observation. In consequence of the latter, the needle in the same place is subject to diurnal variations : in our latitudes the end that points to the north moves slowly westward during the forenoon, and returns to its mean position about ten in the evening; it then deviates to the eastward and again returns to its mean position about ten in the morning.

M. Kupffer of Casan ascertained that there is a nocturnal as well as a diurnal variation, depending in his opinion upon a variation in the magnetic equator. Magnetic storms, or sudden and great but transient disturbances, take place occasionally in the compass, which are per-

turbed. Another property of a magnet is the attraction of unmagnetized iron. Both poles of a magnet attract iron, which in return attracts either pole of the magnet with an equal and contrary force. The magnetic intensity is most powerful at the poles, as may easily be seen by dipping the magnet into iron filings, which will adhere abundantly to each pole, while scarcely any attach themselves to the intermediate parts. The action of the magnet on unmagnetized iron is confined to attraction, whereas the reciprocal agency of magnets is characterized by a repulsive as well as an attractive force, for a north pole repels, a north pole, and a south repels a south pole. But a north and a south pole mutually attract one another, which proves that there are two distinct kinds of magnetic forces, directly opposite in their effects, though similar in their mode of action.

Induction is the power which a magnet possesses of exciting temporary or permanent magnetism in such bodies in its vicinity as are capable of receiving it. By this property the mere approach of a magnet renders iron or steel magnetic, the more powerfully the less the distance. When the north pole of a magnet is brought near to, and in the line with, an unmagnetized iron bar, the bar acquires all the properties of a perfect magnet; the end next the north pole of the magnet becomes a south pole, while the remote end becomes a north pole. Exactly the reverse takes place when the south pole is presented to the bar; so that each pole of a magnet induces the opposite polarity in the adjacent end of the bar, and the same polarity in the remote extremity; consequently the nearest extremity of the bar is attracted, and the farther repelled; but as the action is greater on the adjacent than on the distant part, the resulting force is that of attraction. By induction, the iron bar not only acquires polarity, but the power of inducing magnetism in a third body; and although all these properties vanish from the iron as soon as the magnet is removed, a lasting increase of intensity is generally imparted to the magnet itself by the reaction of the temporary magnetism of the iron. Iron acquires magnetism more rapidly than steel, yet it loses it as

quickly on the removal of the magnet, whereas the steel is impressed with a lasting polarity.

A certain time is requisite for the induction of magnetism, and it may be accelerated by anything that excites a vibratory motion in the particles of the steel, such as the smart stroke of the hammer, or heat succeeded by sudden cold. A steel bar may be converted into a magnet by the transmission of an electric discharge through it; and as its efficacy is the same in whatever direction the electricity passes, the magnetism arises from its mechanical operation exciting a vibration among the particles of steel. It has been observed that the particles of iron easily resume their neutral state after induction, but that those of steel resist the restoration of magnetic equilibrium, or a return to the neutral state; it is therefore evident, that any cause which removes or diminishes the resistance of the particles will tend to destroy the magnetism of the steel; consequently, the same mechanical means which develop magnetism will also destroy it. On that account a steel bar may lose its magnetism by any mechanical concussion, such as by falling on a hard substance, a blow with a hammer, and heating to redness, which reduces the steel to a state of softness. The circumstances which determine whether it shall gain or lose, are its position with respect to the magnetic equator, and the higher or lower intensity of its previous magnetic state.

Polarity of one kind only cannot exist in any portion of iron or steel; in whatever manner the intensities of the two kinds of polarity may be diffused through a magnet, they exactly balance or compensate one another. The northern polarity is confined to one-half of a magnet, and the southern to the other, and they are generally concentrated in or near the extremities of the bar. When a magnet is broken across its middle, each fragment is at once converted into a perfect magnet; the part which originally had a north pole acquires a south pole at the fractured end; the part that originally had a south pole gets a north pole; and as far as mechanical division can be carried, it is found that each fragment, however small, is a perfect magnet.

A comparison of the number of vibrations accomplished

y the same needle, during the same time, at different distances from a magnet, gives the law of magnetic intensity, which follows the inverse ratio of the squares of the distances,—a law that is not affected by the intervention of any substance whatever between the magnet and the needle, provided that substance be not itself susceptible of magnetism. Induction and the reciprocal action of magnets are therefore subject to the laws of mechanics; but the composition and resolution of the forces are complicated, in consequence of four forces being constantly in activity, two in each magnet.

Mr. Were Fox, who has paid much attention to this branch of the science, has lately discovered that the law of the magnetic force changes from the inverse squares of the distances, to the simple inverse ratio, when the distance between two magnets is as small as from the fourth to the eighth of an inch, or even as much as half an inch when the magnets are large. He found, that in the case of repulsion, the change takes place at a still greater distance, especially when the two magnets differ materially in intensity.

There can hardly be a doubt but that all the phenomena of magnetism, like those of electricity, may be explained on the hypothesis of one ethereal fluid, which is condensed or redundant in the positive pole, and deficient in the negative; a theory that accords best with the simplicity and general nature of the laws of creation; nevertheless, Baron Poisson has adopted the hypothesis of two extremely rare fluids pervading all the particles of iron, and incapable of leaving them. Whether the particles of these fluids are coincident with the molecules of the iron, or that they only fill the interstices between them, is unknown and immaterial. But it is certain that the sum of all the magnetic molecules, added to the sum of all the spaces between them, whether occupied by matter or not, must be equal to the whole volume of the magnetic body. When the two fluids in question are combined they are inert, so that the substances containing them show no signs of magnetism; but when separate they are active, the molecules of each of the fluids attracting those of the opposite kind, and repelling those of the same kind. The decomposition of the united

fluids is accomplished by the inductive influence of either of the separate fluids; that is to say, a ferruginous body acquires polarity by the approach of either the south or north pole of the magnet.   The magnetic fluids pervade each molecule of the mass of bodies, and in all probability the electric fluid does the same, though it appears to be confined to the surface; if so, a compensation must take place among the internal forces.   The electric fluid has a perpetual tendency to escape, and does escape, when not prevented by the coercive power of the surrounding air and other non-conducting bodies.   Such a tendency does not exist in the magnetic fluids, which never quit the substance that contains them under any circumstances whatever; nor is any sensible quantity of either kind of polarity ever transferred from one part to another of the same piece of steel.   It appears that the two magnetic fluids, when decomposed by the influence of magnetizing forces, only undergo a displacement to an insensible degree within the body.   The action of all the particles so displaced upon a particle of the magnetic fluid in any particular situation, compose a resultant force, the intensity and direction of which it is the province of the analyst to determine.   In this manner M. Poisson has proved that the result of the action of all the magnetic elements of a magnetized body, is a force equivalent to the action of a very thin stratum covering the whole surface of a body, and consisting of the two fluids—the austral and the boreal, occupying different parts of it; in other words, the attractions and repulsions externally exerted by a magnet, are exactly the same as if they proceeded from a very thin stratum of each fluid occupying the surface only, both fluids being in equal quantities, and so distributed that their total action upon all the points in the interior of the body is equal to nothing.   Since the resulting force is the difference of the two polarities, its intensity must be greatly inferior to that of either.

In addition to the forces already mentioned, there must be some coercive force analogous to friction, which arrests the particles of both fluids, so as first to oppose their separation, and then to prevent their reunion.   In soft iron the coercive force is either wanting or ex-

tremely feeble, since the iron is easily rendered mag-
netic by induction, and as easily loses its magnetism;
whereas in steel the coercive force is extremely ener-
getic, because it prevents the steel from acquiring the
magnetic properties rapidly, and entirely hinders it
from losing them when acquired. The feebleness of
the coercive force in iron, and its energy in steel, with
regard to the magnetic fluids, is perfectly analogous to
the facility of transmission afforded to the electric fluid
by non-electrics, and the resistance it experiences in
electrics. At every step the analogy between magnet-
ism and electricity becomes more striking. The agency
of attraction and repulsion is common to both; the pos-
itive and negative electricities are similar to the northern
and southern polarities, and are governed by the same
laws, namely, that between like powers there is repul-
sion, and between unlike powers there is attraction.
Each of these four forces is capable of acting most ener-
getically when alone; but as the electric equilibrium is
restored by the union of the two electric states, and
magnetic neutrality by the combination of the two polar-
ities, they respectively neutralize each other when
joined. All these forces vary inversely as the squares
of the distances, and consequently come under the same
mechanical laws. A like analogy extends to magnetic
and electrical induction. Iron and steel are in a state of
equilibrium when the two magnetic polarities conceived
to reside in them are equally diffused throughout the
whole mass, so that they are altogether neutral. But
this equilibrium is immediately disturbed on the approach
of the pole of a magnet, which by induction transfers
one kind of polarity to one end of the iron or steel bar,
and the opposite kind to the other—effects exactly simi-
lar to electrical induction. There is even a correspond-
ence between the fracture of a magnet and that of an
electric conductor; for if an oblong conductor be elec-
trified by induction, its two extremities will have opposite
electricities; and if in that state it be divided across the
middle, the two portions, when removed to a distance
from one another, will each retain the electricity that
has been induced upon it. The analogy, however, does
not extend to transference. A body may transfer a re-

dundant quantity of positive electricity to another, or deprive another of its electricity, the one gaining at the expense of the other; but there is no instance of a body possessing only one kind of polarity. With this exception, there is such perfect correspondence between the theories of magnetic attractions and repulsions and electric forces in conducting bodies, that they not only are the same in principle, but are determined by the same formulæ. Experiment concurs with theory in proving the identity of these two unseen influences. Hence if the electrical phenomena be due to a modification of the ethereal medium, the magnetic phenomena must be owing to an analogous cause, and therefore, notwithstanding the high authority of M. Poisson, they must also be attributed to the redundancy and defect of only one fluid.

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With reference to the subject of this chapter I have received the following information from Colonel Sabine, one of the best authorities in this branch of science.

The passage marked (*A*) confounds under the common term of "magnetic pole," two things which are alike distinct in conception and different in reality. These are, 1st—the localities on the globe where the needle is vertical, or the horizontal force 0; and 2d— the localities where the magnetic forces acting on the surface of the globe have a maximum intensity, around which the isodynamic lines on the surface arrange themselves in curves, and in departing from which in every direction (on the surface) the intensity of the force is found to decrease.

The progress of terrestrial magnetism has been greatly impeded by mistakes arising from the different understandings which different people have of what is meant by the term magnetic pole. It is the more important to have *clear ideas* and a correct knowledge of facts in this matter, because the facts of science are not such as in any respect to justify a confusion of terms; not one of the localities where the intensity of the force is a maximum coincides with a position where the dip is 90°; nor does a dip of 90° anywhere coincide with a position where the force is a maximum.

There is in each hemisphere one locality where the

dip is 90°, and two localities where the force forms a
center of greatest intensity around which the isodynamic
lines arrange themselves.   The localities of dip 90° are
rather spaces than points : they are the major axes of
small ovals on the surface of the sphere ; consequently
they are linear rather than circular spaces.   The spot
where Captain Ross observed the needle so nearly ver-
tical in 1831 marks the approximate position of that lo-
cality at that epoch.   This position is, as Mrs. Som-
erville states, about 70° north, and 97° west.   The
isodynamic centers in the same hemisphere are situ-
ated, one in America, the other in Siberia.   The ob-
servations made anterior to 1837, which are collected
and arranged in Colonel Sabine's report to the British
Association of that year, gave, when treated by M.
Gauss according to the formation of the "Allgemeine
Theorie," the American maximum in 55° north and 97°
west, and the Siberian in 71° north and 116° east.   The
more recent observations of Messrs. Lefroy and Locke,
who have traveled in America expressly for the more
accurate determination of what appears so important a
datum in terrestrial physics, and whose results are at
this moment being arranged on a chart on which Colonel
Sabine is about to trace the lines of highest intensity in
America, show that the center of those curves is yet
farther to the southward by some degrees (consequently
still more removed from the position where the dip is
90°) than was supposed in 1837.

   The two maxima of force are not of equal strength :
the Siberian is somewhat the weaker of the two.   The
positions of both undergo secular change, and both in
the same direction, viz. to the eastward.   The secular
change of the weaker or Siberian maximum is far more
considerable than that of the other.   The secular
changes of the isoclinal and isogonic curves correspond
with those of the two systems of forces indicated by
distinct maxima having unequal movements of transla-
tion.   The higher isoclinal curves are oval, having their
major axes in the line of direction joining the two points
of maximum intensity.   The general arrangement in the
south hemisphere is strictly analogous : but the two
centers of force are at this epoch separated by a less in-

terval of longitude than in the north hemisphere. Their respective longitudes, derived from the observations of the antarctic expedition which Colonel Sabine has reduced and published in the Phil. Trans., are approximately 130° and 220° east. The latitudes are not derivable from the observations with equal approximation; but they do not appear to differ much from the corresponding latitudes in the north; *i. e.* the stronger about 50° or 55° south, and the weaker about 70° south. Here also the weaker maximum has a very considerable secular movement, amounting, as Colonel Sabine has given reason to believe in the Phil. Trans. of last year, to nearly 50° of longitude in 250 years: the secular change in the southern hemisphere being to the westward, while that in the northern is to the eastward.

The dip of 90° is far removed from either of these localities; its approximate position may be called about 73° south and 147° east; but the isoclinal curve of 89° will doubtless be more correctly given when the Pagoda returns from the completion of the survey, and when the whole of the observations in the southern hemisphere are combined and treated according to the formulæ of the " Allgemeine Theorie."

The object of the geographical branch of the magnetic observations of the last few years has been to obtain determinations, with the improved instruments of the present time, in every accessible part of the globe, with a view of combining the results into magnetic charts of the three elements drawn directly from the observations, and corresponding to the present epoch. The Magnetic Atlas will then be recomputed by the methods described in Gauss' " Allgemeine Theorie." The observation part is nearly accomplished.

(*a*) This is by no means established; the distribution of land and water appears to have considerable influence on the form of the magnetic equator, as Mrs. Somerville states at (*b*).

(*c*) In the balance of torsion, the intensity of electrical forces is not measured by oscillations, but by the torsion necessary to destroy the deviation produced.

(*d*) Refer to note (*A*).

Section XXXI.

Discovery of Electro-Magnetism—Deflection of the Magnetic Needle by a Current of Electricity—Direction of the Force—Rotatory Motion by Electricity—Rotation of a Wire and a Magnet—Rotation of a Magnet about its Axis—Of Mercury and Water—Electro-Magnetic Cylinder or Helix—Suspension of a Needle in a Helix—Electro-Magnetic Induction—Temporary Magnets—The Galvanometer.

THE disturbing effects of the aurora borealis and lightning on the mariner's compass had been long known. In the year 1819, M. Oersted, Professor of Natural Philosophy at Copenhagen, discovered that a current of Voltaic electricity exerts a powerful influence on a magnetized needle. This observation has given rise to the theory of electro-magnetism—the most interesting science of modern times, whether it be considered as leading us a step farther in generalization, by identifying two agencies hitherto referred to different causes, or as developing a new force, unparalleled in the system of the world, which, overcoming the retardation from friction, and the obstacle of a resisting medium, maintains a perpetual motion, often vainly attempted, but apparently impossible to be accomplished by means of any other force or combination of forces than the one in question.

When the two poles of a Voltaic battery are connected by a metallic wire, so as to complete a circuit, the electricity flows without ceasing. If a straight portion of that wire be placed parallel to, and horizontally above, a magnetized needle at rest in the magnetic meridian, but freely poised like the mariner's compass, the action of the electric current flowing through the wire will instantly cause the needle to change its position. Its extremity will deviate from the north toward the east or west, according to the direction in which the current is flowing; and on reversing the direction of the current, the motion of the needle will be reversed also. The numerous experiments that have been made on the magnetic and electric fluids, as well as those on the various relative motions of a magnetic needle under the influence of galvanic electricity, arising from all possible

positions of the conducting wire, and every direction of
the Voltaic current, together with all the other phe-
nomena of electro-magnetism, are explained by Dr.
Roget in some excellent articles on these subjects in the
Library of Useful Knowledge.

All the experiments tend to prove that the force
emanating from the electric current, which produces
such effects on the magnetic needle, acts at right angles
to the current, and is therefore unlike any force hith-
erto known. The action of all the forces in nature is
directed in straight lines, as far as we know; for the
curves described by the heavenly bodies result from the
composition of two forces; whereas that which is ex-
erted by an electrical current upon either pole of a
magnetic has no tendency to cause the pole to approach
or recede, but to rotate about it. If the stream of elec-
tricity be supposed to pass through the center of a circle
whose plane is perpendicular to the current, the di-
rection of the force exerted by the electricity will always
be in the tangent to the circle, or at right angles to its
radius (N. 217). Consequently the tangential force of
the electricity has a tendency to make the pole of a
magnet move in a circle round the wire of the battery.
Mr. Barlow has proved that the action of each particle
of the electric fluid in the wire, on each particle of the
magnetic fluid in the needle, varies inversely as the
squares of the distances.

Rotatory motion was suggested by Dr. Wollaston.
Dr. Faraday was the first who actually succeeded in
making the pole of a magnet rotate about a vertical
conducting wire. In order to limit the action of the
electricity to one pole, about two-thirds of a small mag-
net were immersed in mercury, the lower end being
fastened by a thread to the bottom of the vessel con-
taining the mercury. When the magnet was thus floating
almost vertically with its north pole above the surface, a
current of positive electricity was made to descend per-
pendicularly through a wire touching the mercury, and
immediately the magnet began to rotate from left to
right about the wire. The force being uniform, the
rotation was accelerated till the tangential force was
balanced by the resistance of the mercury, when it be-

two metals soldered together. It is truly wonderful that an agent, evolved by so small an instrument, and diffused through a large mass of iron, should communicate a force which seems so disproportionate. Steel needles are rendered permanently magnetic by electrical induction; the effect is produced in a moment, and as readily by juxtaposition as by contact; the nature of the poles depends upon the direction of the current, and the intensity is proportional to the quantity of electricity.

It appears that the principle and characteristic phenomena of the electro-magnetic science are, the evolution of a tangential and rotatory force exerted between a conducting body and a magnet; and the transverse induction of magnetism by the conducting body in such substances as are susceptible of it.

The action of an electric current causes a deviation of the compass from the plane of the magnetic meridian. In proportion as the needle recedes from the meridian, the intensity of the force of terrestrial magnetism increases, while at the same time the electro-magnetic force diminishes; the number of degrees at which the needle stops, showing where the equilibrium between these two forces takes place, will indicate the intensity of the galvanic current. The galvanometer, constructed upon this principle, is employed to measure the intensity of galvanic currents collected and conveyed to it by wires. This instrument is rendered much more sensible by neutralizing the effects of the earth's magnetism on the needle, which is accomplished by placing a second magnetized needle so as to counteract the action of the earth on the first—a precaution requisite in all delicate magnetical experiments.

Electro-magnetic induction has been elegantly and usefully employed by Professor Wheatstone as a moving power in a telegraph, by which intelligence is conveyed in a time quite inappreciable, since the electricity would make the circuit of the globe in the tenth of a second.

Section XXXII.

THE science of electro-magnetism, which must render the name of M. Oersted ever memorable, relates to the reciprocal action of electrical and magnetic currents: M. Ampère, by discovering the mutual action of electrical currents on one another, has added a new branch to the subject, to which he has given the name of electro-dynamics.

When electric currents are passing through two conducting wires, so suspended or supported as to be capable of moving both toward and from one another, they show mutual attraction or repulsion, according as the currents are flowing in the same or in contrary directions; the phenomena varying with the relative inclinations and positions of the streams of electricity. The mutual action of such currents, whether they flow in the same or in contrary directions, whether they be parallel, perpendicular, diverging, converging, circular, or heliacal, all produce different kinds of motion in a conducting wire, both rectilineal and circular, and also the rotation of a wire helix, such as that described, now called an electro-dynamic cylinder, on account of some improvements in its construction (N. 219). And as the hypothesis of a force varying inversely as the squares of the distances accords perfectly with all the observed phenomena, these motions come under the same laws of dynamics and analysis as any other branch of physics.

Electro-dynamic cylinders act on each other precisely as if they were magnets during the time the electricity is flowing through them. All the experiments that can be performed with the cylinder might be accomplished with a magnet. That end of the cylinder in which the current of positive electricity is moving in a direction similar to the motion of the hands of a watch, acts as the south pole of a magnet, and the other end, in which the

current is flowing in a contrary direction, exhibits north-
ern polarity.

The phenomena mark a very decided difference be-
tween the action of electricity in motion or at rest, that
is, between Voltaic and common electricity; the laws
they follow are in many respects of an entirely different
nature, though the electricities themselves are identical.
Since Voltaic electricity flows perpetually, it cannot be
accumulated, and consequently has no tension, or ten-
dency to escape from the wires which conduct it. Nor
do these wires either attract or repel light bodies in
their vicinity, whereas ordinary electricity can be accu-
mulated in insulated bodies to a great degree, and in
that state of rest the tendency to escape is proportional
to the quantity accumulated and the resistance it meets
with. In ordinary electricity, the law of action is that
dissimilar electricities attract, and similar electricities
repel one another. In Voltaic electricity, on the con-
trary, similar currents, or such as are moving in the
same direction, attract one another, while a mutual re-
pulsion is exerted between dissimilar currents, or such
as flow in opposite directions. Common electricity
escapes when the pressure of the atmosphere is re-
moved, but the electro-dynamical effects are the same
whether the conductors be in air or in vacuo.

The effects produced by a current of electricity de-
pend upon the celerity of its motion through a conduct-
ing wire. Yet we are ignorant whether the motion be
uniform or varied, but the method of transmission has a
marked influence on the results; for when it flows with-
out intermission, it occasions a deviation in the magnetic
needle, but it has no effect whatever when its motion is
discontinuous or interrupted, like the current produced
by the common electrical machine when a communica-
tion is made between the positive and negative con-
ductors.

M. Ampère has established a theory of electro-mag-
netism suggested by the analogy between electro-dy-
namic cylinders and magnets, founded upon the recip-
rocal attraction of electric currents, to which all the phe-
nomena of magnetism and electro-magnetism may be
reduced, by assuming that the magnetic properties

which bodies possess derive these properties from currents of electricity circulating about every part in one uniform direction.   Although every particle of a magnet possesses like properties with the whole, yet the general effect is the same as if the magnetic properties were confined to the surface.   Consequently the internal electro-currents must compensate one another, and therefore the magnetism of a body is supposed to arise from a superficial current of electricity constantly circulating in a direction perpendicular to the axes of the magnet; so that the reciprocal action of magnets, and all the phenomena of electro-magnetism, are reduced to the action and reaction of superficial currents of electricity acting at right angles to their direction.   Notwithstanding the experiments made by M. Ampère to elucidate the subject, there is still an uncertainty in the theory of the induction of magnetism by an electric current in a body near it.   It does not appear whether electric currents which did not previously exist are actually produced by induction, or if its effects be only to give one uniform direction to the infinite number of electric currents previously existing in the particles of the body, and thus rendering them capable of exhibiting magnetic phenomena, in the same manner as polarization reduces those undulations of light to one plane which had previously been performed in every plane.   Possibly both may be combined in producing the effect; for the action of an electric current may not only give a common direction to those already existing, but may also increase their intensity.   However that may be, by assuming that the attraction and repulsion of the elementary portions of electric currents vary inversely as the squares of the distances, the action being at right angles to the direction of the current, it is found that the attraction and repulsion of a current of indefinite length on the elementary portion of a parallel current at any distance from it, is in the simple ratio of the shortest distance between them.   Consequently the reciprocal action of electric currents is reduced to the composition and resolution of forces, so that the phenomena of electro-magnetism are brought under the laws of dynamics by the theory of M. Ampère.

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was made to revolve rapidly, the galvanometer needle
was deflected sometimes as much as 90°, and, by a uni-
form rotation, the deflection was constantly maintained
at 45°.   When the motion of the copper plate was re-
versed, the needle was deflected in the contrary direc-
tion, and thus a permanent current of electricity was
evolved by an ordinary magnet.   The intensity of the
electricity collected by the wires, and conveyed by them
to the galvanometer, varied with the position of the
plate relatively to the poles of the magnet.

The motion of the electricity in the copper plate may
be conceived by considering, that merely by moving a
single wire like the spoke of a wheel before a magnetic
pole, a current of electricity tends to flow through it
from one end to the other.   Hence, if a wheel be con-
structed of a great many such spokes, and revolved
near the pole of a magnet in the manner of the copper
disc, each radius or spoke will tend to have a current
produced in it as it passes the pole.   Now, as the
circular plate is nothing more than an infinite number
of radii or spokes in contact, the currents will flow in
the direction of the radii if a channel be open for their
return, and in a continuous plate that channel is afforded
by the lateral portions on each side of the particular
radius close to the magnetic pole.   This hypothesis is
confirmed by observation, for the currents of positive
electricity set from the center to the circumference, and
the negative from the circumference to the center, and
vice versâ, according to the position of the magnetic
poles and the direction of rotation.   So that a collecting
wire at the center of the copper plate conveys positive
electricity to the galvanometer in one case, and negative
in another; that collected by a conducting wire in con-
tact with the circumference of the plate is always the
opposite of the electricity conveyed from the center.
It is evident that when the plate and magnet are both
at rest, no effect takes place, since the electric currents
which cause the deflection of the galvanometer cease
altogether.   The same phenomena may be produced by
electro-magnets.   The effects are similar when the
magnet rotates and the plate remains at rest.   When
the magnet revolves uniformly, about its own axis, elec-

fested, a brilliant spark takes place every time the copper point leaves the surface of the mercury. Platina wire is ignited, shocks smarts enough to be disagreeable are given, and water is decomposed with astonishing rapidity by the same means; which proves beyond a doubt the identity of the magnetic and electric agencies, and places Dr. Faraday, whose experiments established the principle, in the first rank of experimental philosophers.

Section XXXIV.

Electricity produced by Rotation—Direction of the Currents—Electricity from the Rotation of a Magnet—M. Arago's Experiment explained—Rotation of a Plate of Iron between the Poles of a Magnet—Relation of Substances to Magnets of three kinds—Thermo-Electricity.

M. Arago discovered an entirely new source of magnetism in rotatory motion. If a circular plate of copper be made to revolve immediately above or below a magnetic needle or magnet, suspended in such a manner that the magnet may rotate in a plane parallel to that of the copper plate, the magnet tends to follow the circumvolution of the plate; or if the magnet revolves, the plate tends to follow its motion: so powerful is the effect, that magnets and plates of many pounds weight have been carried round. This is quite independent of the motion of the air, since it is the same when a pane of glass is interposed between the magnet and the copper. When the magnet and the plate are at rest, not the smallest effect, attractive, repulsive, or of any kind, can be perceived between them. In describing this phenomenon, M. Arago states that it takes place not only with metals, but with all substances, solids, liquids, and even gases, although the intensity depends upon the kind of substance in motion. Experiments made by Dr. Faraday explain this singular action. A plate of copper, twelve inches in diameter and one-fifth of an inch thick, was placed between the poles of a powerful horseshoe magnet, and connected at certain points with a galvanometer by copper wires. When the plate was at rest no effect was produced; but as soon as the plate

discovered that electric currents may be produced by
the partial application of heat to a circuit formed of two
solid conductors. For example, when a semicircle of
bismuth, joined to a semicircle of antimony, so as to form
a ring, is heated at one of the junctions by a lamp, a
current of electricity flows through the circuit from the
antimony to the bismuth, and such thermo-electric cur-
rents produce all the electro-magnetic effects. A com-
pass needle placed either within or without the circuit,
and at a small distance from it, is deflected from its na-
tural position, in a direction corresponding to the way in
which the electricity is flowing. If such a ring be sus-
pended so as to move easily in any direction, it will obey
the action of a magnet brought near it, and may even
be made to revolve. According to the researches of M.
Seebeck, the same substance, unequally heated, exhibits
electrical currents; and M. Nobili observed, that in all
metals, except zinc, iron, and antimony, the electricity
flows from the hot part toward that which is cold. That
philosopher attributes terrestrial magnetism to a differ-
ence in the action of heat on the various substances of
which the crust of the earth is composed; and in con-
firmation of his views he has produced electrical currents
by the contact of two pieces of moist clay, of which one
was hotter than the other.

M. Becquerel constructed a thermo-electric battery of
one kind of metal, by which he has determined the re-
lation between the heat employed and the intensity of
the resulting electricity. He found that in most metals
the intensity of the current increases with the heat to a
certain limit, but that this law extends much farther in
metals that are difficult to fuse, and which do not rust.
The experiments of Professor Cumming show that the
mutual action of a magnet and a thermo-electric current
is subject to the same laws as those of magnets and gal-
vanic currents, consequently all the phenomena of repul-
sion, attraction, and rotation may be exhibited by a thermo-
electric current. M. Botto, of Turin, has decomposed
water and some solutions by thermo-electricity; and
very recently the Cav. Antinori of Florence has suc-
ceeded in obtaining a brilliant spark with the aid of an
electro-dynamic coil.

The principle of thermo-electricity has been employed by MM. Nobili and Melloni for measuring extremely minute quantities of heat in their experiments on the instantaneous transmission of radiant caloric. The thermo-multiplier, which they constructed for that purpose, consists of a series of alternate bars, or rather fine wires of bismuth and antimony, placed side by side, and the extremities alternately soldered together. When heat is applied to one end of this apparatus, the other remaining at its natural temperature, currents of electricity flow through each pair of bars, which are conveyed by wires to a delicate galvanometer, the needle of which points out the intensity of the electricity conveyed, and consequently that of the heat employed. This instrument is so delicate that the comparative warmth of different insects has been ascertained by means of it.

Section XXXV.

The Action of Terrestrial Magnetism upon Electric Currents—Induction of Electric Currents by Terrestrial Magnetism—The Earth Magnetic by Induction—Mr. Barlow's Experiment of an Artificial Sphere—The Heat of the Sun the Probable Cause of Electric Currents in the Crust of the Earth ; and of the Variations in Terrestrial Magnetism—Electricity of Metallic Veins—Terrestrial Magnetism possibly owing to Rotation—Magnetic Properties of the Celestial Bodies—Identity of the Five Kinds of Electricity—Connection between Light, Heat, and Electricity or Magnetism.

In all the experiments hitherto described, artificial magnets alone were used ; but it is obvious that the magnetism of the terrestrial spheroid, which has so powerful an influence on the mariner's compass, must also affect electrical currents. It consequently appears that a piece of copper wire bent into a rectangle, and free to revolve on a vertical axis, arranges itself with its plane at right angles to the magnetic meridian, as soon as a stream of electricity is sent through it. Under the same circumstances a similar rectangle, suspended on a horizontal axis at right angles to the magnetic meridian, assumes the same inclination with the dipping needle ; so that terrestrial magnetism has the same influence on electrical currents as an artificial magnet. But the magnetic action of the earth also induces electric cur-

by their relative electrical conditions, but that the direction of the metallic veins must have been influenced by the direction of the magnetic meridians; and in fact almost all the metallic deposits in the world tend from east to west, or from northeast to southwest. Though it is impossible to say in the present state of our knowledge, how far the sun may be concerned in the phenomena of terrestrial magnetism, it is probable that the secular and periodic disturbances in the magnetic force are occasioned by a variety of other combining circumstances. Among these M. Biot mentions the vicinity of mountain chains to the place of observation, and still more the action of extensive volcanic fires, which change the chemical state of the terrestrial surface, they themselves varying from age to age, some becoming extinct, while others burst into activity. Should the ethereal medium which fills space be the same with the electric fluid, as M. Mossotti supposes, may not the heat of the sun rarefy it at the earth's equator, and thus by the inequality of its distribution, and its superior density at the poles, occasion some of the magnetic phenomena of the globe? and may not the sun's motion in declination cause temporary variations of density in the fluid, and produce periodic changes in the magnetic equator and intensity? Were this the case, all the planets would be magnets like the earth, being precisely in similar circumstances.

It is moreover probable, that terrestrial magnetism may be owing, in a certain extent, to the earth's rotation. Dr. Faraday has proved that all the phenomena of revolving plates may be produced by the inductive action of the earth's magnetism alone. If a copper plate be connected with a galvanometer by two copper wires, one from the center and another from the circumference, in order to collect and convey the electricity, it is found that when the plate revolves in a plane passing through the line of the dip, the galvanometer is not affected. But as soon as the plate is inclined to that plane, electricity begins to be developed by its rotation; it becomes more powerful as the inclination increases, and arrives at a maximum when the plate revolves at right angles to the line of the dip. When the revolution is in the same

direction with that of the hands of a watch, the current of electricity flows from its center to the circumference; and when the rotation is in the opposite direction, the current sets the contrary way. The greatest deviation of the galvanometer amounted to 50° or 60°, when the direction of the rotation was accommodated to the oscillations of the needle. Thus a copper plate, revolving in a plane at right angles to the line of the dip, forms a new electrical machine, differing from the common plate-glass machine, by the material of which it is composed being the most perfect conductor, whereas glass is the most perfect non-conductor; besides, insulation, which is essential in the glass machine, is fatal in the copper one. The quantity of electricity evolved by the metal does not appear to be inferior to that developed by the glass, though very different in intensity.

From the experiments of Dr. Faraday, and also from theory, it is possible that the rotation of the earth may produce electric currents in its own mass. In that case, they would flow superficially in the meridians, and if collectors could be applied at the equator, and poles, as in the revolving plate, negative electricity would be collected at the equator, and positive at the poles; that is to say, there would be a deficiency at the equator and a redundancy at the poles; but without something equivalent to conductors to complete the circuit, these currents could not exist.

Since the motion, not only of metals but even of fluids, when under the influence of powerful magnets, evolves electricity, it is probable that the gulf-stream may exert a sensible influence upon the forms of the lines of magnetic variation, in consequence of electric currents moving across it, by the electro-magnetic induction of the earth. Even a ship, passing over the surface of the water in northern or southern latitudes, ought to have electric currents running directly across the line of her motion. Dr. Faraday observes, that such is the facility with which electricity is evolved by the earth's magnetism, that scarce any piece of metal can be moved in contact with others without a development of it, and consequently, among the arrangements of steam-engines and metallic machinery, curious electro-magnetic com-

its composition, by means of magnetic action; and M. Botto of Turin has shown the chemical effects of the thermo-electricity in the decomposition of water, and some other substances. The electric and galvanic shock, the flash in the eyes, and the sensation on the tongue, are well known. All these effects are produced by magneto-electricity, even to a painful degree. The torpedo and gymnotus electricus give severe shocks, and the limbs of a frog have been convulsed by thermo-electricity. The last point of comparison is the spark, which is common to the ordinary Voltaic and magnetic fluids; and Professor Linari, of Siena, has very lately obtained both the direct and induced sparks from the torpedo, proving that in this respect animal electricity does not differ from the others. Indeed, the conclusion drawn by Dr. Faraday is that the five kinds of electricity are identical, and that the differences of intensity and quantity are quite sufficient to account for what were supposed to be their distinctive qualities. He has given still greater assurance of their identity by showing that the magnetic force and the chemical action of electricity are in direct proportion to the absolute quantity of the fluid which passes through the galvanometer, whatever its intensity may be.

In light, heat, and electricity, or magnetism, nature has exhibited principles which do not occasion any appreciable change in the weight of bodies, although their presence is manifested by the most remarkable mechanical and chemical action. These agencies are so connected, that there is reason to believe they will ultimately be referred to some one power of a higher order, in conformity with the general economy of the system of the world, where the most varied and complicated effects are produced by a small number of universal laws. These principles penetrate matter in all directions; their velocity is prodigious, and their intensity varies inversely as the squares of the distances. The development of electric currents, as well by magnetic as electric induction, the similarity in their mode of action in a great variety of circumstances, but above all, the production of the spark from a magnet, the ignition of metallic wires, and chemical decomposition, show that

magnetism can no longer be regarded as a separate independent principle. Although the evolution of light and heat during the passage of the electric fluid may be from the compression of the air, yet the development of electricity by heat, the influence of heat on magnetic bodies, and that of light on the vibration of the compass, show an occult connection between all these agents, which probably will one day be revealed. In the mean time it opens a noble field of experimental research to philosophers of the present, perhaps of future ages.

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SECTION XXXVI.

Ethereal Medium—Comets—Do not disturb the Solar System—Their Orbits and Disturbances—M. Faye's Comet, probably the same with Lexel's—Periods of other three known—Halley's—Acceleration in the Mean Motions of Encke's and Biela's Comets—The Shock of a Comet—Disturbing Action of the Earth and Planets on Encke's and Biela's Comets—Velocity of Comets—The Great Comet of 1843—Physical Constitution—Shine by borrowed Light—Estimation of their Number.

In considering the constitution of the earth and the fluids which surround it, various subjects have presented themselves to our notice, of which some, for aught we know, are confined to the planet we inhabit; some are common to it and to the other bodies of our system. But an all-pervading ether probably fills the whole visible creation, and conveys, in the form of light, tremors which may have been excited in the deepest recesses of the universe thousands of years before we were called into being. The existence of such a medium, though at first hypothetical, is nearly proved by the undulatory theory of light, and rendered all but certain within a few years by the motion of comets, and by its action upon the vapors of which they are chiefly composed. It has often been imagined that, in addition to the effects of heat and electricity, the tails of comets have infused new substances into our atmosphere. Possibly the earth may attract some of that nebulous matter, since the vapors raised by the sun's heat, when the comets are in perihelio, and which form their tails, are scattered through space in their passage to their aphelion; but it has hitherto produced no effect, nor have

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the seasons ever been influenced by these bodies. The light of the comet of the year 1811, which was so brilliant, did not impart any heat even when condensed on the bulb of a thermometer, of a structure so delicate that it would have made the hundredth part of a degree evident. In all probability, the tails of comets may have passed over the earth without its inhabitants being conscious of their presence; and there is reason to believe that the tail of the great comet of 1843 did so.

The passage of comets has never sensibly disturbed the stability of the solar system; their nucleus, being in general only a mass of vapor, is so rare, and their transit so rapid, that the time has not been long enough to admit of a sufficient accumulation of impetus to produce a perceptible action. Indeed M. Dusejour has proved, that under the most favorable circumstances, a comet cannot remain longer than two hours and a half at a less distance from the earth than 10,500 leagues. The comet of 1770 passed within about six times the distance of the moon from the earth, without even affecting our tides. According to La Place, the action of the earth on the comet of 1770 augmented the period of its revolution by more than two days; and if comets had any perceptible disturbing energy, the reaction of the comet ought to have increased the length of our year. Had the mass of that comet been equal to the mass of the earth, its disturbing action would have increased the length of the sidereal year by $2^h 53^m$; but as Delambre's computations from the Greenwich observations of the sun show that the length of the year has not been increased by the fraction of a second, its mass could not have been equal to the $\frac{1}{5000}$th part of that of the earth. This accounts for the same comet having twice swept through the system of Jupiter's satellites without deranging the motion of these moons. M. Dusejour has computed that a comet, equal in mass to the earth, passing at the distance of 12,150 leagues from our planet, would increase the length of the year to $367^d 16^h 5^m$, and the obliquity of the ecliptic as much as $2°$. So the principal action of comets would be to alter the calendar, even if they were dense enough to affect the earth.

Comets traverse all parts of the heavens; their paths

have every possible inclination to the plane of the eclip-
tic, and, unlike the planets, the motion of more than
half of those that have appeared has been retrograde,
that is, from east to west.   They are only visible when
near their perihelia; then their velocity is such, that its
square is twice as great as that of a body moving in a
circle at the same distance : they consequently remain
but a very short time within the planetary orbits.   And
as all the conic sections of the same focal distance sen-
sibly coincide, through a small arc, on each side of the
extremity of their axis, it is difficult to ascertain in which
of these curves the comets move, from observations
made, as they necessarily must be, at their perihelia
(N. 220).   Probably they all move in extremely eccen-
tric ellipses; although in most cases the parabolic curve
coincides most nearly with their observed motions.
Some few seem to describe hyperbolas; such, being once
visible to us, would vanish forever, to wander through
boundless space, to the remote systems of the universe.
If a planet be supposed to revolve in a circular orbit, the
radius of which is equal to the perihelion distance of a
comet moving in a parabola, the areas described by these
two bodies in the same time will be as unity to the
square root of two, which forms such a connection be-
tween the motion of comets and planets, that by Kep-
ler's law, the ratio of the areas described during the
same time by the comet and the earth may be found.
So that the place of a comet may be computed at any
time in its parabolic orbit, estimated from the instant of
its passage at the perihelion.   It is a problem of very
great difficulty to determine all the other elements of
parabolic motion—namely, the comet's perihelion dis-
tance, or shortest distance from the sun, estimated in
parts of the mean distance of the earth from the sun;
the longitude of the perihelion; the inclination of the
orbit on the plane of the ecliptic; and the longitude of
the ascending node.   Three observed longitudes and
latitudes of a comet are sufficient for computing the ap-
proximate values of these quantities; but an accurate
estimation of them can only be obtained by successive
corrections, from a number of observations, distant from
one another.   When the motion of a comet is retrograde,

the place of the ascending node is exactly opposite to
what it is when the motion is direct. Hence the place
of the ascending node, together with the direction of the
comet's motion, show whether the inclination of the
orbit is on the north or south side of the plane of the
ecliptic. If the motion be direct, the inclination is on
the north side; if retrograde, it is on the south side.

The identity of the elements is the only proof of the
return of a comet to our system. Should the elements
of a new comet be the same, or nearly the same, with
those of any one previously known, the probability of
the identity of the two bodies is very great, since the
similarity extends to no less than four elements, every
one of which is capable of an infinity of variations. But
even if the orbit be determined with all the accuracy the
case admits of, it may be difficult, or even impossible,
to recognize a comet on its return, because its orbit
would be very much changed if it passed near any of
the large planets of this or of any other system, in con-
sequence of their disturbing energy, which would be
very great on bodies of so rare a nature.

By far the most curious and interesting instance of
the disturbing action of the great bodies of our system
is found in the comet of 1770. The elements of its or-
bit, determined by Messier, did not agree with those of
any comet that had hitherto been computed, yet Lexel
ascertained that it described an ellipse about the sun,
whose major axis was only equal to three times the
length of the diameter of the terrestrial orbit, and con-
sequently that it must return to the sun at intervals of
five years and a half. This result was confirmed by
numerous observations, as the comet was visible through
an arc of 170°; yet this comet had never been observed
before the year 1770, nor has it ever again been seen
till 1843, though very brilliant. The disturbing action
of the larger planets affords a solution of this anomaly,
as Lexel ascertained that in 1767 the comet must have
passed Jupiter at a distance less than the fifty-eighth
part of its distance from the sun, and that in 1779 it
would be 500 times nearer Jupiter than the sun; conse-
quently the action of the sun on the comet would not be
the fiftieth part of what it would experience from Jupi-

ter, so that Jupiter became the primum mobile.   As-
suming the orbit to be such as Lexel had determined in
1770, La Place found that the action of Jupiter, previ-
ous to the year 1770, had so completely changed the
form of it, that the comet which had been invisible to us
before 1770, was then brought into view, and that the
action of the same planet producing a contrary effect,
has subsequently to that year removed it from our sight,
since it was computed to be revolving in an orbit whose
perihelion was beyond the orbit of Ceres.   However,
the action of Jupiter during the summer of 1840 must
have been so great, from his proximity to that singular
body, that he seems to have brought it back to its former
path, as he had done in 1767, for the elements of the
orbit of a comet which was discovered in November,
1843, by M. Faye, agree so nearly with those of the
orbit of Lexel's comet as to leave scarcely a doubt of
their identity.   From the smallness of the eccentricity,
the orbit resembles those of the planets, but this comet
is liable to greater perturbations than any other body in
the system, because it comes very near the orbit of
Mars when in perihelion, and very near that of Jupiter
when in aphelion; besides, it passes within a compara-
tively small distance of the orbits of the minor planets,
and as it will continue to cross the orbit of Jupiter at
each revolution till the two bodies meet, its periodic
time, now about seven years, will again be changed, but
in the mean time it ought to return to its perihelion in
the year 1851.   This comet might have been seen from
the earth in 1776, had its light not been eclipsed by that
of the sun.   It is quite possible that comets frequenting
our system may be turned away, or others brought to
the sun, by the attraction of planets revolving beyond
the orbit of Uranus, or by bodies still farther removed
from the solar influence.

Other three comets, liable to less disturbance, return
to the sun at stated intervals.   Halley computed the
elements of the orbit of a comet that appeared in the
year 1682, which agreed so nearly with those of the
comets of 1607 and 1531, that he concluded it to be the
same body returning to the sun at intervals of about
seventy-five years.   He consequently predicted its re-

appearance in the year 1758, or in the beginning of
1759. Science was not sufficiently advanced in the time
of Halley, to enable him to determine the perturbations
this comet might experience; but Clairaut computed,
that in consequence of the attraction of Jupiter and
Saturn, its periodic time would be so much shorter than
during its revolution between 1607 and 1682, that it
would pass its perihelion on the 18th of April, 1759.
The comet did arrive at that point of its orbit on the 12th
of March, which was thirty-seven days before the time
assigned. Clairaut subsequently reduced the error to
twenty-three days; and La Place has since shown that
it would only have been thirteen days if the mass of
Saturn had been as well known as it is now. It appears
from this, that the path of the comet was not quite known
at that period; and although many observations were
then made, they were far from attaining the accuracy of
those of the present day. Besides, since the year 1759
the orbit of the comet has been altered by the attraction
of Jupiter in one direction, and that of the earth, Saturn,
and Uranus, in the other; yet, notwithstanding these
sources of uncertainty, and our ignorance of all the pos-
sible causes of derangement from unknown bodies on
the confines of our system, or in the regions beyond it,
the comet has appeared exactly at the time, and not far
from the place, assigned to it by astronomers; and its
actual arrival at its perihelion a little before noon on the
16th of November, 1835, only differed from the com-
puted time by a very few days.

The fulfilment of this astronomical prediction is truly
wonderful if it be considered that the comet is seen only
for a few weeks, during its passage through our system,
and that it wanders from the sun for seventy-five years
to twice the distance of Uranus. This enormous orbit
is four times longer than it is broad; its length is about
3420 millions of miles, or about thirty-six times the mean
distance of the earth from the sun. At its perihelion
the comet comes within nearly fifty-seven millions of
miles of the sun, and at its aphelion it is sixty times
more distant. On account of this extensive range it
must experience 3600 times more light and heat when
nearest to the sun than in the most remote point of its

orbit. In the one position the sun will seem to be four times larger than he appears to us, and at the other he will not be apparently larger than a star (N. 221).

On the first appearance of Halley's comet, early in August, 1835, it seemed to be merely a globular mass of dim vapor, without a tail. A concentration of light, a little on one side of the center, increased as the comet approached the sun and earth, and latterly looked so like the disc of a small planet, that it might have been mistaken for a solid nucleus. M. Struve, however, saw a central occultation of a star of the ninth magnitude by the comet, at Dorpat, on the 29th of September. The star remained constantly visible, without any considerable diminution of light; and instead of being eclipsed, the nucleus of the comet disappeared at the moment of conjunction from the brilliancy of the star. The tail increased as the comet approached its perihelion, and shortly before it was lost in the sun's rays, it was between thirty and forty degrees in length.

According to the observations of M. Valz, of Nismes, the nebulosity increased in magnitude as it approached the sun; but no other comet on record has exhibited such sudden and unaccountable changes of aspect. The nucleus, clear and well defined, like the disc of a planet, was observed on one occasion to become obscure and enlarged in the course of a few hours. But by far the most remarkable circumstance was the sudden appearance of certain luminous brushes or sectors, diverging from the center of the nucleus through the nebulosity. M. Struve describes the nucleus of the comet, in the beginning of October, as elliptical, and like a burning coal, out of which there issued, in a direction nearly opposite to the tail, a divergent flame, varying in intensity, form, and direction, appearing occasionally even double, and suggesting the idea of luminous gas bursting from the nucleus. On one occasion M. Arago saw three of these divergent flames on the side opposite the tail, rising through the nebulosity, which they greatly exceeded in brilliancy: after the comet had passed its perihelion, it acquired another of these luminous fans, which was observed by Sir John Herschel at the Cape of Good Hope. Hevelius describes an appearance precisely similar,

which he had witnessed in this comet at its approach to the sun in the year 1682, and something of the kind seems to have been noticed in the comet of 1744. Possibly the second tail of the comet of 1724, which was directed toward the sun, may have been of this nature.

The influence of the ethereal medium on the motions of Halley's comet, will be known after another revolution, and future astronomers will learn, by the accuracy of its returns, whether it has met with any unknown cause of disturbance in its distant journey. Undiscovered planets, beyond the visible boundary of our system, may change its path and the period of its revolution, and thus may indirectly reveal to us their existence, and even their physical nature and orbit. The secrets of the yet more distant heavens may be disclosed to future generations by comets which penetrate still farther into space, such as that of 1763, which, if any faith may be placed in the computation, goes nearly forty-three times farther from the sun than Halley's does, and shows that the sun's attraction is powerful enough, at the enormous distance of 15,500 millions of miles, to recall the comet to its perihelion. The periods of some comets are said to be of many thousand years, and even the average time of the revolution of comets generally is about a thousand years; which proves that the sun's gravitating force extends very far. La Place estimates that the solar attraction is felt throughout a sphere whose radius is a hundred millions of times greater than the distance of the earth from the sun.

Authentic records of Halley's comet do not extend beyond the year 1456, yet it may be traced, with some degree of probability, even to a period preceding the Christian era. But as the evidence only rests upon coincidences of its periodic time, which may vary as much as eighteen months from the disturbing action of the planets, its identity with comets of such remote times must be regarded as extremely doubtful.

This is the first comet whose periodicity has been established. It is also the first whose elements have been determined from observations made in Europe; for although the comets which appeared in the years 240, 539, 565, and 837, are the most ancient of those whose

orbits have been traced, their elements were computed from Chinese observations.

Besides Halley's and Lexel's comets, two others are now proved to form part of our system ; that is to say, they return to the sun at intervals, one of three years, and the other of 6¾ years nearly. The first, generally called Encke's comet, or the comet of the short period, was first seen by MM. Messier and Mechain, in 1786, again by Miss Herschel in 1805, and its returns, in the years 1805 and 1819, were observed by other astronomers, under the impression that all four were different bodies. However, Professor Encke not only proved their identity, but determined the circumstances of the comet's motion. Its reappearance in the years 1825, 1828, and 1832, accorded with the orbit assigned by M. Encke, who thus established the length of its period to be 1204 days, nearly. This comet is very small, of feeble light, and invisible to the naked eye, except under very favorable circumstances, and in particular positions. It has no tail, it revolves in an ellipse of great eccentricity inclined at an angle of 13° 22′ to the plane of the ecliptic, and is subject to considerable perturbations from the attraction of the planets, which occasion variations in its periodic time. Among the many perturbations to which the planets are liable, their mean motions, and therefore the major axes of their orbits, experience no change ; while on the contrary, the mean motion of the moon is accelerated from age to age—a circumstance at first attributed to the resistance of an ethereal medium pervading space, but subsequently proved to arise from the secular diminution of the eccentricity of the terrestrial orbit. Although the resistance of such a medium has not hitherto been perceived in the motions of such dense bodies as the planets and satellites, its effects on the revolutions of the two small periodic comets hardly leave a doubt of its existence. From the numerous observations that have been made on each return of the comet of the short period, the elements have been computed with great accuracy on the hypothesis of its moving in vacuo. Its perturbations occasioned by the disturbing action of the planets have been determined ; and after everything

that could influence its motion had been duly considered,
M. Encke found that an acceleration of about two days
in each revolution has taken place in its mean motion,
precisely similar to that which would be occasioned by
the resistance of an ethereal medium.   And as it cannot
be attributed to a cause like that which produces the
acceleration of the moon, it must be concluded that the
celestial bodies do not perform their evolutions in an
absolute void, and that although the medium be too rare
to have a sensible effect on the masses of the planets
and satellites, it nevertheless has a considerable influ-
ence on so rare a body as a comet.   Contradictory as it
may seem, that the motion of a body should be accele-
rated by the resistance of an ethereal medium, the
truth becomes evident if it be considered that both
planets and comets are retained in their orbits by two
forces which exactly balance one another; namely, the
centrifugal force producing the velocity in the tangent,
and the attraction of the gravitating force directed to
the center of the sun.   If one of these forces be dimin-
ished by any cause, the other will be proportionally
increased.   Now, the necessary effect of a resisting
medium is to diminish the tangential velocity, so that
the balance is destroyed, gravity preponderates, the
body descends toward the sun till equilibrium is again
restored between the two forces; and as it then de-
scribes a smaller orbit it moves with increased velocity.
Thus, the resistance of an ethereal medium actually
accelerates the motion of a body; but as the resisting
force is confined to the plane of the orbit, it has no in-
fluence whatever on the inclination of the orbit, or on
the place of the nodes.   In computing its effect, M.
Encke assumed the increase to be inversely as the
squares of the distances, and that its resistance acts as a
tangential force proportional to the squares of the
comet's actual velocity in each point of its orbit.   The
other comet belonging to our system, which returns to
its perihelion after a period of $6\frac{3}{4}$ years, has been ac-
celerated in its motion by a whole day during its last
revolution, which puts the existence of ether nearly
beyond a doubt, and forms a strong presumption in cor-
roboration of the undulatory theory of light.   Since this

comet, which revolves nearly between the orbits of the earth and Jupiter, is only accelerated one day at each revolution, while Encke's, revolving nearly between the orbits of Mercury and Pallas, is accelerated two, the ethereal medium must increase in density toward the sun.   The comet in question was discovered by M. Biela at Johannisberg on the 27th of February, 1826, and ten days afterward it was seen by M. Gambart at Marseilles, who computed its parabolic elements, and found that they agreed with those of the comets which had appeared in the years 1789 and 1795, whence he concluded them to be the same body moving in an ellipse, and accomplishing its revolution in 2460 days. The perturbations of this comet were computed by M. Damoiseau, who predicted that it would cross the plane of the ecliptic on the 29th of October, 1832, a little before midnight, at a point nearly 18,484 miles within the earth's orbit; and as M. Olbers of Bremen, in 1805, had determined the radius of the comet's head to be about 21,136 miles, it was evident that its nebulosity would envelop a portion of the earth's orbit, a circumstance which caused some alarm in France, from the notion that if any disturbing cause had delayed the arrival of the comet for one month, the earth must have passed through its head.   M. Arago dispelled these fears by his excellent treatise on comets in the Annuaire of 1832, where he proves, that as the earth would never be nearer the comet than 18,000,000 British leagues, there could be no danger of collision. The earth is in more danger from these two small comets than from any other.   Encke's crosses the terrestrial orbit sixty times in a century, and may ultimately come into collision; but both are so extremely rare, that little injury is to be apprehended.

The earth would fall to the sun in 64½ days, if it were struck by a comet with sufficient impetus to destroy its centrifugal force.   What the earth's primitive velocity may have been, it is impossible to say.   Therefore a comet may have given it a shock without changing the axis of rotation, but only destroying part of its tangential velocity, so as to diminish the size of the orbit—a thing by no means impossible, though highly improbable.

Indeed, comets in general are subject to sudden and violent convulsions in their interior, even when far from the sun, which produce changes that are visible at enormous distances, and baffle all attempts at explanation,—probably arising from electricity, or even causes with which we are unacquainted. The envelops surrounding the nucleus of the comet on the side next to the sun, diverge on the opposite side, where they are prolonged into the form of a hollow cone, which is the tail. Two repulsive forces seem to be concerned in producing this effect; one from the comet and another from the sun, the latter being the most powerful. The envelops are nearer the center of the comet on the side next to the sun, where these forces are opposed to one another: but on the other side the forces conspire to form the tail, conveying the nebulous particles to enormous distances.

The lateral edges of the tail reflect more light than the central part, because the line of vision passes through a greater depth of nebulous matter, which produces the effect of two streams somewhat like the aurora. Stars shine with undiminished lustre through the central part of the tail, because their rays traverse it perpendicularly to its thickness; but though distinctly seen through its edges, their light is weakened by its oblique transmission. The tail of the great comet of 1811 was of wonderful tenuity; stars which would have been entirely concealed by the slightest fog, were seen through 64,000 leagues of nebulous matter without the smallest refraction. Possibly some part of the changes in the appearance of the tails arises from rotation. Several comets have been observed to rotate about an axis passing through the center of the tail. That of 1825 performed its rotation in $20\frac{1}{2}$ hours, and the rapid changes in the luminous sectors which issued from the nucleus of Halley's comet, in all probability were owing to rotatory motion.

The two streams of light which form the edges of the tail, in most cases unite at a greater or less distance from the nucleus, and are generally situate in the plane of the orbit. The tails follow comets in their descent toward the sun, but precede them in their return, with

Every twenty-third year, or after seven revolutions of Encke's comet, its greatest proximity to Jupiter takes place, and at that time his attraction increases the period of its revolution by nine days—a circumstance which took place in the end of the years 1820 and 1843. But from the position of the bodies there is a diminution of three days in the six following revolutions, which reduces the increase to six days in seven revolutions. Thus before the year 1819, the periodic time of Encke's comet was 1204 days, and it was 1219 days in accomplishing its last revolution, which terminated in 1845. By this progressive increase the orbit of the comet will reach that of Jupiter in seven or eight centuries, and then by the very near approach of the two bodies it will be completely changed.

At present the earth and Mercury have the most powerful influence on the motions of Encke's and Biela's comets ; and have had for so long a time that, according to the computation of Mr. Airy, the present orbit of the latter was formed by the attraction of the earth, and that of Encke's by the action of Mercury.   With regard to the latter comet, that event must have taken place in February, 1776.   In 1786 Encke's comet had both a tail and a nucleus, now it has neither ; a singular instance of the possibility of their disappearance.

Comets in or near their perihelion move with prodigious velocity.   That of 1680 appears to have gone half round the sun in ten hours and a half, moving at the rate of 880,000 miles an hour.   If its enormous centrifugal force had ceased when passing its perihelion, it would have fallen to the sun in about three minutes, as it was then less than 147,000 miles from his surface.   So near the sun, it would be exposed to a heat 27,500 times greater than that received by the earth ; and as the sun's heat is supposed to be in proportion to the intensity of his light, it is probable that a degree of heat so intense would be sufficient to convert into vapor every terrestrial substance with which we are acquainted. At the perihelion distance the sun's diameter would be seen from the comet under an angle of 73°, so that the sun, viewed from the comet, would nearly cover the whole extent of the heavens from the horizon to the

zenith. As this comet is presumed to have a period of 575 years, the major axis of its orbit must be so great, that at the aphelion the sun's diameter would only subtend an angle of about fourteen seconds, which is not so great by half as the diameter of Mars appears to us when in opposition. The sun would consequently impart no heat, so that the comet would then be exposed to the temperature of the ethereal regions, which is 58° below the zero point of Fahrenheit. A body of such tenuity as the comet, moving with such velocity, must have met with great resistance from the dense atmosphere of the sun, while passing so near his surface at its perihelion. The centrifugal force must consequently have been diminished, and the sun's attraction proportionally augmented, so that it must have come nearer to the sun in 1680 than in its preceding revolution, and would subsequently describe a smaller orbit. As this diminution of its orbit will be repeated at each revolution, the comet will infallibly end by falling on the surface of the sun, unless its course be changed by the disturbing influence of some large body in the unknown expanse of creation. Our ignorance of the actual density of the sun's atmosphere, of the density of the comet, and of the period of its revolution, renders it impossible to form any idea of the number of centuries which must elapse before this event takes place.

The same cause may affect the motions of the planets, and ultimately be the means of destroying the solar system. But, as Sir John Herschel observes, they could hardly all revolve in the same direction round the sun for so many ages without impressing a corresponding motion on the ethereal fluid, which may preserve them from the accumulated effects of its resistance. Should this material fluid revolve about the sun like a vortex, it will accelerate the revolutions of such comets as have direct motions, and retard those that have retrograde motions.

The comet which appeared unexpectedly in the beginning of the year 1843, was one of the most splendid that ever visited the solar system. It was in the constellation of Antinous in the end of January, at a distance of 115 millions of miles from the earth, and it

passed through its perihelion on the 27th of February, when it was lost in the sun's rays; but it began to be visible about the 3d of March, at which time it was near the star Iota Cetæ, and its tail extended toward the Hare. The brightness of the comet and the length of its tail continued to increase till the latter stretched far beyond the constellation of the Hare toward a point above Sirius. Stars were distinctly seen through it, and when near perihelion the comet was so bright that it was seen in clear sunshine in the United States like a white cloud. The motion was retrograde, and on leaving the solar system it retreated so rapidly at once from the sun and earth that it was soon lost sight of for want of light. On the 1st of April it was between the sun and the earth, and only 40 millions of miles from the latter; and as its tail was at least 60 millions of miles long, and 20 millions of miles broad, we probably passed through it without being aware of it. There is some discrepancy in the different computations of the elements of the orbit, but in the greater number of cases the perihelion distance was found to be less than the semidiameter of the sun, so that the comet must have grazed his surface, if it did not actually impinge obliquely on him.

The perihelion distance of this comet differs little from that of the great comet of 1668, which came so near the sun. The motion of both was retrograde, and a certain resemblance in the two orbits makes it probable that they are the same body performing a revolution in 175 years.

Though already so well acquainted with the motions of comets, we know nothing of their physical constitution. A vast number, especially of telescopic comets, are only like clouds or masses of vapor, often without tails. Such were the comets which appeared in the years 1795, 1797, and 1798. But the head commonly consists of a concentrated mass of light, like a planet, surrounded by a very transparent atmosphere, and the whole, viewed with a telescope, is so diaphanous, that the smallest star may be seen even through the densest part of the nucleus; in general their solid parts, if they have any, are so minute, that they have no sensible

light has never been satisfactorily made out till now.
Even if the light of a comet were polarized, it would
not afford a decisive test, since a body is capable of re-
flecting light though it shines by its own.   M. Arago,
however, has with great ingenuity discovered a method
of ascertaining this point, independent both of phases
and polarization.

Since the rays of light diverge from a luminous point,
they will be scattered over a greater space as the dis-
tance increases, so that the intensity of the light on a
screen two feet from the object, is four times less than
at the distance of one foot; three feet from the object
it is nine times less, and so on, decreasing in intensity
as the squares of the distances increase.   As a self-
luminous surface consists of an infinite number of lumi-
nous points, it is clear that the greater the extent of sur-
face, the more intense will be the light; whence it may
be concluded that the illuminating power of such a sur-
face is proportional to its extent, and decreases inversely
as the squares of the distances.   Notwithstanding this,
a self-luminous surface, plane or curved, viewed through
a hole in a plate of metal, is of the same brilliancy at all
possible distances as long as it subtends a sensible angle,
because, as the distance increases, a greater portion
comes into view, and as the augmentation of surface is
as the square of the diameter of the part seen through
the hole, it increases as the squares of the distances.
Hence, though the number of rays from any one point
of the surface which pass through the hole, decreases
inversely as the squares of the distances, yet, as the
extent of surface which comes into view increases also
in that ratio, the brightness of the object is the same to
the eye as long as it has a sensible diameter.   For ex-
ample—Uranus is about nineteen times farther from the
sun than we are, so that the sun, seen from that planet,
must appear like a star with a diameter of a hundred
seconds, and must have the same brilliancy to the inhab-
itants that he would have to us if viewed through a
small circular hole having a diameter of a hundred sec-
onds.   For it is obvious that light comes from every
point of the sun's surface to Uranus, whereas a very
small portion of his disc is visible through the hole ; so

that extent of surface exactly compensates distance.
Since, then, the visibility of a self-luminous object does
not depend upon the angle it subtends as long as it is
of sensible magnitude, if a comet shines by its own light,
it should retain its brilliancy as long as its diameter is of
a sensible magnitude ; and even after it has lost an ap-
parent diameter, it ought to be visible, like the fixed
stars, and should only vanish in consequence of extreme
remoteness.   That, however, is far from being the case
—comets gradually become dim as their distance in-
creases, and vanish merely from loss of light, while
they still retain a sensible diameter, which is proved by
observations made the evening before they disappear.
It may therefore be concluded, that comets shine by
reflecting the sun's light.   The most brilliant comets
have hitherto ceased to be visible when about five times
as far from the sun as we are.   Most of the comets
that have been visible from the earth have their peri-
helia within the orbit of Mars, because they are invisible
when as distant as the orbit of Saturn : on that account
there is not one on record whose perihelion is situate
beyond the orbit of Jupiter.   Indeed, the comet of 1756,
after its last appearance, remained five whole years
within the ellipse described by Saturn without being
once seen.   More than a hundred and forty comets
have appeared within the earth's orbit during the last
century that have not again been seen.   If a thousand
years be allowed as the average period of each, it may
be computed, by the theory of probabilities, that the
whole number which range within the earth's orbit
must be 1400 ; but Uranus being about nineteen times
more distant, there may be no less than 11,200,000
comets that come within the known extent of our sys-
tem.   M. Arago makes a different estimate : he con-
siders that, as thirty comets are known to have their
perihelion distance within the orbit of Mercury, if it be
assumed that comets are uniformly distributed in space,
the number having their perihelion within the orbit of
Uranus must be to thirty as the cube of the radius of
the orbit of Uranus to the cube of the radius of the
orbit of Mercury, which makes the number of comets
amount to 3,529,470.   But that number may be doubled,

that could influence its motion had been duly considered,
M. Encke found that an acceleration of about two days
in each revolution has taken place in its mean motion,
precisely similar to that which would be occasioned by
the resistance of an ethereal medium. And as it cannot
be attributed to a cause like that which produces the
acceleration of the moon, it must be concluded that the
celestial bodies do not perform their evolutions in an
absolute void, and that although the medium be too rare
to have a sensible effect on the masses of the planets
and satellites, it nevertheless has a considerable influ-
ence on so rare a body as a comet. Contradictory as it
may seem, that the motion of a body should be accele-
rated by the resistance of an ethereal medium, the
truth becomes evident if it be considered that both
planets and comets are retained in their orbits by two
forces which exactly balance one another; namely, the
centrifugal force producing the velocity in the tangent,
and the attraction of the gravitating force directed to
the center of the sun. If one of these forces be dimin-
ished by any cause, the other will be proportionally
increased. Now, the necessary effect of a resisting
medium is to diminish the tangential velocity, so that
the balance is destroyed, gravity preponderates, the
body descends toward the sun till equilibrium is again
restored between the two forces; and as it then de-
scribes a smaller orbit it moves with increased velocity.
Thus, the resistance of an ethereal medium actually
accelerates the motion of a body; but as the resisting
force is confined to the plane of the orbit, it has no in-
fluence whatever on the inclination of the orbit, or on
the place of the nodes. In computing its effect, M.
Encke assumed the increase to be inversely as the
squares of the distances, and that its resistance acts as a
tangential force proportional to the squares of the
comet's actual velocity in each point of its orbit. The
other comet belonging to our system, which returns to
its perihelion after a period of $6\frac{3}{4}$ years, has been ac-
celerated in its motion by a whole day during its last
revolution, which puts the existence of ether nearly
beyond a doubt, and forms a strong presumption in co
roboration of the undulatory theory of light.   Since th

if it be considered that, in consequence of daylight, fogs, and great southern declination, one comet out of two must be hid from us. According to M. Arago, more than seven millions of comets frequent the planetary orbits.

The different degrees of velocity with which the planets and comets were originally propelled in space is the sole cause of the diversity in the form of their orbits, which depends only upon the mutual relation between the projectile force and the sun's attraction.

When the two forces are exactly equal to one another, circular motion is produced; when the ratio of the projectile to the central force is exactly that of 1 to the square root of 2, the motion is parabolic; any ratio between these two will cause a body to move in an ellipse, and any ratio greater than that of 1 to the square root of 2 will produce hyperbolic motion (N. 222).

The celestial bodies might move in any one of these four curves by the law of gravitation; but as one particular velocity is necessary to produce either circular or parabolic motion, such motions can hardly be supposed to exist in the solar system, where the bodies are liable to such mutual disturbances as would infallibly change the ratio of the forces, and cause them to move in ellipses in the first case, and hyperbolas in the other. On the contrary, since every ratio between equality and that of 1 to the square root of 2 will produce elliptical motion, it is found in the solar system in all its varieties, from that which is nearly circular, to such as borders on the parabolic from excessive ellipticity. On this depends the stability of the system; the mutual disturbances only cause the orbits to become more or less eccentric without changing their nature.

For the same reason the bodies of the solar system might have moved in an infinite variety of hyperbolas, since any ratio of the forces, greater than that which causes parabolic motion, will make a body move in one of these curves. Hyperbolic motion is however very rare; only two comets appear to move in orbits of that nature, those of 1771 and 1824; probably all such comets have already come to their perihelia, and consequently will never return.

The ratio of the forces which fixed the nature of the celestial orbits is thus easily explained ; but the circumstances which determined these ratios, which caused some bodies to move nearly in circles and others to wander toward the limits of the solar attraction, and which made all the heavenly bodies to rotate and revolve in the same direction, must have had their origin in the primeval state of things ; but as it pleases the Supreme Intelligence to employ gravitation alone in the maintenance of this fair system, it may be presumed to have presided at its creation.

Section XXXVII.

The Fixed Stars—Their Numbers—Estimation of their Distances and Magnitudes from their Light—Stars that have vanished—New Stars—Double Stars—Binary and Multiple Systems—Their Orbits and Periods—Orbitual and Parallactic Motions—Colors—Proper Motions—General Motions of all the Stars—Clusters—Nebulæ—Their Number and Forms—Double and Stellar Nebulæ—Nebulous Stars—Planetary Nebulæ—Constitution of the Nebulæ, and Forces which maintain them—Distribution—Meteorites—Shooting Stars.

GREAT as the number of comets appears to be, it is absolutely nothing when compared with the multitude of the fixed stars. About 2000 only are visible to the naked eye ; but when we view the heavens with a telescope, their number seems to be limited only by the imperfection of the instrument. In one hour Sir William Herschel estimated that 50,000 stars passed through the field of his telescope, in a zone of the heavens 2° in breadth. This, however, was stated as an instance of extraordinary crowding ; but, on an average, the whole expanse of the heavens must exhibit about a hundred millions of fixed stars within the reach of telescopic vision.

The stars are classed according to their apparent brightness, and the places of the most remarkable of those visible to the naked eye are ascertained with great precision, and formed into a catalogue, not only for the determination of geographical positions by their occultations, but to serve as points of reference for marking the places of comets and other celestial phe-

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nomena. The whole number of stars registered amounts to about 150,000 or 200,000. The distance of the fixed stars is too great to admit of their exhibiting a sensible disc; but in all probability they are spherical, and most certainly be so if gravitation pervades all space, which it may be presumed to do, since Sir John Herschel has shown that it extends to the binary systems of stars. With a fine telescope the stars appear like a point of light; their occultations by the moon are therefore instantaneous. Their twinkling arises from sudden changes in the refractive powers of the air, which would not be sensible if they had discs like the planets. Thus we can learn nothing of the relative distances of the stars from us, and from one another, by their apparent diameters. The annual parallax of all but a very few being insensible, shows we must be more than two hundred millions of millions of miles at least from them. Many of them, however, must be vastly more remote; for of two stars that appear close together, one may be far beyond the other in the depth of space. The light of Sirius, according to the observations of Sir John Herschel, is 324 times greater than that of a star of the sixth magnitude; if we suppose the two to be really of the same size, their distances from us must be in the ratio of 57·3 to 1, because light diminishes as the square of the distance of the luminous body increases.

Nothing is known of the absolute magnitude of the fixed stars, but the quantity of light emitted by many of them shows that they must be much larger than the sun. Dr. Wollaston determined the approximate ratio which the light of a wax candle bears to that of the sun, moon, and stars, by comparing their respective images reflected from small glass globes filled with mercury, whence a comparison was established between the quantities of light emitted by the celestial bodies themselves. By this method he found that the light of the sun is about twenty millions of millions of times greater than that of Sirius, the brightest and one of the nearest of the fixed stars. Since the parallax of Sirius is about half a second, its distance from the earth must be 592,200 times the distance of the sun from the earth; and *therefore* Sirius, placed where the sun is, would appear

to us to be 3·7 times as large as the sun, and would give
13·8 times more light.   Many of the fixed stars must be
infinitely larger than Sirius.

   Many stars have vanished from the heavens; the
star 42 Virginis seems to be of this number, having been
missed by Sir John Herschel on the 9th of May, 1828,
and not again found, though he frequently had occasion
to observe that part of the heavens.   Sometimes stars
have all at once appeared, shone with a bright light,
and vanished.   Several instances of these temporary
stars are on record; a remarkable instance occurred in
the year 125, which is said to have induced Hipparchus
to form the first catalogue of stars.   Another star ap-
peared suddenly near a Aquilæ in the year 389, which
vanished, after remaining for three weeks as bright as
Venus.   On the 10th of October, 1604, a brilliant star
burst forth in the constellation of Serpentarius, which
continued visible for a year; and a more recent case
occurred in the year 1670, when a new star was discov-
ered in the head of the Swan, which, after becoming
invisible, reappeared, and having undergone many varia-
tions in light, vanished after two years, and has never
since been seen.   In 1572 a star was discovered in Cas-
siopeia, which rapidly increased in brightness till it even
surpassed that of Jupiter; it then gradually diminished
in splendor, and having exhibited all the variety of tints
that indicate the changes of combustion, vanished sixteen
months after its discovery, without altering its position.
It is impossible to imagine anything more tremendous
than a conflagration that could be visible at such a dis-
tance.   It is however suspected that this star may be
periodical, and identical with the stars which appeared
in the years 945 and 1264.   There are probably many
stars which alternately vanish and reappear among the
innumerable multitudes that spangle the heavens; the
periods of several have already been pretty well ascer-
tained.   Of these the most remarkable is the star Omi-
cron, in the constellation Cetus.   It appears about twelve
times in eleven years, and is of variable brightness, some-
times appearing like a star of the second magnitude;
but it does not always attain the same lustre, nor does
it *increase* or *diminish* by the same degrees.   Accord-

ing to Hevelius, it did not appear at all for four years.
γ Hydræ also vanishes and reappears every 494 days;
and a very singular instance of periodicity is given by
Sir John Herschel, in the star Algol or β Persei, which
is described as retaining the size of a star of the second
magnitude for two days and fourteen hours; it then
suddenly begins to diminish in splendor, and in about
three hours and a half is reduced to the size of a star
of the fourth magnitude; it then begins again to increase,
and in three hours and a half more regains its usual
brightness, going through all these vicissitudes in two
days, twenty hours, and forty-eight minutes. α Cassi-
opeiæ is also periodical, accomplishing its changes in 225
days: the period of the star 34 Cygni is 18 years; and
Sir John Herschel has discovered very singular varia-
tions in the star η of the constellation Argo. It is sur-
rounded by a wonderful nebula, and from a star of little
more than the second magnitude it suddenly increased
between the years 1837 and 1838 to be a first-rate star
of the first magnitude. At the latter period it was equal
to Arcturus, and its brilliancy was then so great as to
obliterate some of the details of the surrounding nebula.
Afterward it decreased to the first magnitude, and then
began to increase again. Sir John has also discovered
that α Orionis may now be classed among the variable
and periodic stars, a circumstance the more remarkable,
as it is one of the conspicuous stars of our hemisphere,
and yet its changes had never been remarked. The
inferences Sir John draws from the phenomena of vari-
able stars are too interesting not to be given in his own
words. " A periodic change existing to so great an ex-
tent in so large and brilliant a star as α Orionis, cannot
fail to awaken attention to the subject, and to revive the
consideration of those speculations respecting the possi-
bility of a change in the lustre of our sun itself which
were put forth by my father. If there really be a com-
munity of nature between the sun and fixed stars, every
proof that we obtain of the extensive prevalence of such
periodical changes in those remote bodies adds to the
probability of finding something of the kind nearer home.
If our sun were ever intrinsically much brighter than at
present, the mean temperature of the surface of our

globe would of course be proportionally greater. I speak now not of periodical but secular changes. But the argument is complicated with the consideration of the possibly imperfect transparency of the celestial spaces, and with the cause of that imperfect transparency which may be due to material non-luminous particles diffused irregularly in patches analogous to nebulæ, but of greater extent—to cosmical clouds in short—of whose existence we have, I think, some indication in the singular and apparently capricious phenomena of temporary stars, and perhaps in the recent extraordinary sudden increase and hardly less sudden diminution of η Argus." Mr. Goodricke has conjectured that the periodical changes in the stars may be occasioned by the revolution of some opaque body coming between us and the star, and obstructing part of its light. Sir John Herschel is struck with the high degree of activity evinced by these changes in regions where, "but for such evidences, we might conclude all to be lifeless." He observes that our own sun requires nine times the period of Algol to perform a revolution on its own axis; while on the other hand, the periodic time of an opaque revolving body sufficiently large to produce a similar temporary obscuration of the sun, seen from a fixed star, would be less than fourteen hours.

Many thousands of stars that seem to be only brilliant points, when carefully examined are found to be in reality systems of two or more suns, sometimes revolving about a common center. These binary and multiple stars are extremely remote, requiring the most powerful telescopes to show them separately. The first catalogue of double stars, in which their places and relative positions are determined, was accomplished by the talents and industry of Sir William Herschel, to whom Astronomy is indebted for so many brilliant discoveries, and with whom the idea of their combination in binary and multiple systems originated — an idea completely established by his own observations, and recently confirmed by those of his son and other astronomers. The motions of revolution of many of these stars round a common center have been ascertained, and their periods determined with considerable accuracy. Some have,

have been extreme, and the apparent angular velocity so great that it might have described an angle of 68° in a single year. Observations made at the Cape of Good Hope, by Sir John Herschel, as well as those of Captain Smyth, R. N., at home, correspond in proving an augmentation of velocity as the star was approaching its shortest distance from its primary. By the laws of elliptical motion, the angular velocity of the revolving star must now gradually diminish, till it comes to its aphelion some 314 years hence. The satellite star of σ Coronæ attained its perihelion in 1835, and that of Castor will do the same some time in 1855.

It sometimes happens that the edge of the orbit of a revolving star is presented to the earth, as in π Serpentarii. Then the star seems to move in a straight line, and to oscillate on each side of its primary. Five observations are requisite in this case for the determination of its orbit, provided they be accurate. At the time Sir William Herschel observed the system in question, the two stars were distinctly separate: at present, one is so completely projected on the other, that M. Struve, with his great telescope, cannot perceive the smallest separation. On the contrary, the two stars of ζ Orionis, which appeared to be one in the time of Sir William Herschel, are now separated. Were this libration owing to parallax, it would be annual, from the revolution of the earth; but as years elapse before it amounts to a sensible quantity, it can only arise from a real orbital motion seen obliquely. Among the triple stars, two of the stars of ζ Cancri revolve about the third. There are also quadruple stars, and there are even assemblages of five and six stars, as θ and σ of Orion. It is remarked that, in general, the ellipses in which the revolving stars of binary systems move, are much more elongated than the orbits of the planets. Sir John Herschel, Sir James South, and Professor Struve of Dorpat, have increased Sir William Herschel's original catalogue of double stars to more than 6000, of which thirty or forty are known to form revolving or binary systems; and Mr. Dunlop has formed a catalogue of 253 double stars in the southern hemisphere. To this Sir John Herschel has added many; but he has found that the southern hemisphere

is poorer than the northern in close double stars above
the tenth magnitude. He observes, that if Mr. Dunlop's
measures can be depended upon, 6 Eridani is perhaps
the most remarkable of all the binary systems in the
heavens. The revolution of the satellite star being at
the rate of 10°·67 per annum, it consequently must
accomplish a revolution in a little more than thirty years.
The motion of Mercury is more rapid than that of any
other planet, being at the rate of 107,000 miles an hour;
the perihelion velocity of the comet of 1680 was no less
than 880,000 miles an hour; but if the two stars of 6
Eridani or ξ Ursæ be as remote from one another as the
nearest fixed star is from the sun, the velocity of the
revolving stars must exceed the powers of imagination.
The discovery of the elliptical motion of the double stars
excites the highest interest, since it shows that gravita-
tion is not peculiar to our system of planets, but that
systems of suns in the far distant regions of the uni-
verse are also obedient to its laws.

Besides revolutions about one another, some of the
binary systems are carried forward in space by a motion
common to both stars, toward some unknown point in
the firmament. The two stars of 61 Cygni, which are
nearly equal, and have remained at the distance of about
15″ from each other for fifty years, have changed their
place in the heavens during that period, by 4′ 23″, with
a motion which for ages must appear rectilinear: be-
cause, even if the path be curved, so small a portion of
it must appear a straight line to us. The single stars
also have proper motions, yet so minute that the trans-
lation of μ Cassiopeiæ, of 3″·74 annually, is the greatest
yet observed: but the enormous distances of the stars
make motions appear small to us which are in reality
very great. Sir William Herschel conceived that,
among many irregularities, the motions of the stars have
a general tendency toward a point diametrically oppo-
site to that occupied by the star ζ Herculis, which he
attributed to a motion of the solar system in the contrary
direction. Should this really be the case, the stars,
from the effects of perspective alone, would seem to
diverge in the direction to which we are tending, and
would apparently converge in the space we leave, and

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there would be a regularity in these apparent motions which would in time be detected; but if the solar system and the whole of the stars visible to us be carried forward in space by a motion common to all, like ships drifting in a current, it would be impossible for us, moving with the rest, to ascertain its direction. There can be no doubt of the progressive motion of the sun and stars, but sidereal astronomy is not far enough advanced to determine what relations these bear to one another; it will however be known in the course of time from the orbits of the revolving stars of the binary systems. For if the solar system be in motion, some of the stellar orbits which, by the effects of perspective, appear to us to be straight lines, will, after a time, open and become elliptical by our change of place; while others which now appear to be open will close, or open wider; stars also which now occultate, or hide one another in certain points of their orbits, will, in time, cease to do so. The directions and magnitude of these changes will no doubt show the motion of our system, to what point it is tending, and the velocity with which it moves.

Among the multitudes of small stars, whether double or insulated, a few are found near enough to exhibit distinct parallactic motions, arising from the revolution of the earth in its orbit. Of two stars apparently in close approximation, one may be far behind the other in space. These may seem near to one another when viewed from the earth in one part of its orbit, but may separate widely when seen from the earth in another position, just as two terrestrial objects appear to be one when viewed in the same straight line, but separate as the observer changes his position. In this case the stars would not have real, but only apparent motion. One of them would seem to oscillate annually to and fro in a straight line on each side of the other—a motion which could not be mistaken for that of a binary system, where one star describes an ellipse about the other, or, if the edge of the orbit be turned toward the earth, where the oscillations require years for their accomplishment.

This method of finding the distances of the fixed stars *was proposed* by Galileo, and attempted by Dr. Long

without success. Sir William Herschel afterward applied it to some of the binary groups; and though he did not find the thing he sought for, it led to the discovery of the orbital motions of the double stars.

Though the absolute distance of most of the stars is still a desideratum, a limit has been found under which, probably, none of them come. It was natural to suppose that in general the large stars are nearer to the earth than the small ones; but there is now reason to believe that some stars, though by no means brilliant, are nearer to us than others which shine with greater splendor. This is inferred from the comparative velocity of their motions. All the stars have a general motion of translation, which tends ultimately to mix the stars of the different constellations, but none that we know of moves so rapidly as 61 Cygni; and on that account it is reckoned to be nearer to us than any other, for an object seems to move more quickly the nearer we are to it. This circumstance induced MM. Arago and Mathieu to endeavor to determine its annual parallax, that is, to ascertain what magnitude the diameter of the earth's orbit would have as seen from the star, and from that to compute its distance from the earth (N. 223). This has been accomplished with more accuracy by M. Bessel, who has found by observation, that the diameter of the earth's orbit of 190 millions of miles would be seen from the star under an angle of only one-third of a second, whence 61 Cygni must be 592,200 times farther from the earth than the sun is, —a distance which light, flying at the rate of 190,000 miles in a second, would not pass over in less than nine years and three months.

The apparent motion of five seconds annually which this star has, seems to us to be extremely small, but at that distance an angle of one second corresponds to twenty-four millions of millions of miles; consequently the annual motion of 61 Cygni is one hundred and twenty millions of millions of miles, and yet, as M. Arago observes, we call it a fixed star!

From the observations of Professor Henderson it appears that Sirius, the brightest star in the heavens, has a parallax of less than the third of a second; conse-

quently it is at a greater distance than 61 Cygni: that of a Centauri amounts to a second of space, so that it is nearer the earth than any star that is known: whereas Mr. Airy has found that the parallax of a Lyræ is altogether inappreciable; and as this is generally the case with the fixed stars, we may conclude that their distances are beyond the hope of mensuration.

All the ordinary methods fail when the distances are so enormous. An angle even of two or three seconds, viewed in the focus of our largest telescopes, does not equal the thickness of a spider's thread, which makes it impossible to measure such minute quantities with any degree of accuracy. In some cases, however, the binary systems of stars furnish a method of estimating an angle of even the tenth of a second, which is thirty times more accurate than by any other means. From them the actual distances of some of the more remote stars will ultimately be known.

Suppose that one star revolves about another in an orbit which is so obliquely seen from the earth as to look like an ellipse in a horizontal position, then it is clear that one half of the orbit will be nearer to us than the other half. Now, in consequence of the time which light takes to travel, we always see the satellite star in a place which it has already left. Hence when that star sets out from the point of its orbit which is nearest to us, its light will take more and more time to come to us in proportion as the star moves round to the most distant point in its orbit. On that account the star will appear to us to take more time in moving through that half of its orbit than it really does. Exactly the contrary takes place in the other half: for the light will take less and less time to arrive at the earth in proportion as the star approaches nearer to us, and therefore it will seem to move through this half of its orbit in less time than it really does. This circumstance furnishes the means of finding the absolute breadth of the orbit in miles, and from that the true distance of the star from the earth. For, since the greatest and least distances of the satellite star from the earth differ by the breadth of its orbit, the time which the star takes to move from the nearest to the remotest point of its orbit is greater than

it ought to be, by the whole time its light takes to cross the orbit, and the period of moving through the other half is exactly as much less.   Hence the difference between the observed times of these two semi-revolutions of the star is equal to twice the time that its light employs to cross its orbit; and as we know the velocity of light, the diameter of the orbit may be found in miles, and from that its whole dimensions.   For the position of the orbit with regard to us is known by observation, as well as the place, inclination, and apparent magnitude of its major axis, or, which is the same thing, the angle under which it is seen from the earth.   Since, then, three things are known in this great triangle, namely, the base or major axis of the orbit in miles, the angle opposite to it at the earth, and the angle it makes with the visual ray; the distance of the satellite star from the earth may be found by the most simple of calculations. The merit of having first proposed this very ingenious method of finding the distances of the stars is due to M. Savary; but unfortunately it is not of general application, as it depends upon the position of the orbit, and even then a long time must elapse before observation can furnish data, since the shortest period of any revolving star that we know of is thirty years : still the distances of a vast number of stars may be ultimately made out in this way; and as one important discovery almost always leads to another, their masses may thus be weighed against that of the earth or sun.

The only data employed for finding the mass of the earth, as compared with that of the sun, are the angular motion of our globe round the sun in a second of time, and the distance of the earth from the sun in miles (N. 224).   Now by the observations of the binary systems, we know the angular velocity of the small star round the great one; and when we know the distance between the two stars in miles, it will be easy to compute how many miles the small star would fall through by the attraction of the great one in a second of time.   A comparison of this space with the space which the earth would descend through in a second toward the sun, will give the ratio of the mass of the great star to that of the sun or earth.

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If it be considered that all the double stars appear single to the naked eye, and with ordinary instruments, and that it requires the highest powers of the very best telescopes to separate the greater number of them, the extreme beauty of the ingenuity and refraction necessary to draw such profound results from their motions may be in some degree appreciated.

The double stars are of various hues, but they most frequently exhibit the contrasted colors. The large star is generally yellow, orange, or red; and the small star blue, purple, or green. Sometimes a white star is combined with a blue or purple, and more rarely a red and white are united. In many cases, these appearances are due to the influence of contrast on our judgment of colors. For example, in observing a double star, where the large one is a full ruby red, or almost blood color, and the small one a fine green, the latter loses its color when the former is hid by the cross wires of the telescope. But there are a vast number of instances where the colors are too strongly marked to be merely imaginary. Sir John Herschel observes in one of his papers in the Philosophical Transactions, as a very remarkable fact, that, although red stars are common enough, no example of a solitary blue, green, or purple one has yet been produced.

The stars are scattered very irregularly over the firmament. In some places they are crowded together, in others thinly dispersed. A few groups more closely condensed form very beautiful objects even to the naked eye, of which the Pleiades and the constellation Coma Berenices are the most striking examples; but the greater number of these clusters of stars appear to unassisted vision like thin white clouds or vapor: such is the milky way, which, as Sir William Herschel has proved, derives its brightness from the diffused light of the myriads of stars that form it. Most of these stars appear to be extremely small, on account of their enormous distances; and they are so numerous, that, according to his estimation, no fewer than 50,000 passed through the field of his telescope in the course of one hour in a zone 2° broad. This singular portion of the heavens, constituting part of our firmament, consists of

an extensive mass of stars, whose thickness is small compared with its length and breadth; the earth is placed near the point where it diverges into two branches, and it appears to be much more splendid in the Southern hemisphere than in the Northern. Sir John Herschel says, " The general aspect of the Southern circumpolar regions (including in that expression 60° or 70° of South polar distance) is in a high degree rich and magnificent, owing to the superior brilliancy and large development of the milky way, which, from the constellation of Orion to that of Antinoüs, is a blaze of light, strangely interrupted, however, with vacant and entirely starless patches, especially in Scorpio, near Alpha Centauri and the Cross, while to the north it fades away pale and dim, and is in comparison hardly traceable. I think it is impossible to view this splendid zone, with the astonishingly rich and evenly distributed fringe of stars of the 3rd and 4th magnitude, which forms a broad skirt to its southern border like a vast curtain, without an impression amounting almost to conviction, that the milky way is not a mere stratum, but annular, or at least that our system is placed within one of the poorer or almost vacant parts of its general mass, and that eccentrically, so as to be much nearer to the region about the Cross, than to that diametrically opposite to it." The cluster, of which our sun is a member, and which includes the milky way, and all the stars that adorn our sky, must be of enormous extent, since the sun is more than two hundred thousand times farther from the nearest of them than he is from the earth; and the other stars, though apparently so close together, are probably separated from one another by distances equally great. In the intervals between the stars of our own system and far in the depths of space, many clusters of stars may be seen like white clouds or round comets without tails, either by unassisted vision or with ordinary telescopes; but, seen with powerful instruments, Sir John Herschel describes them as conveying the idea of a globular space insulated in the heavens and filled full of stars, constituting a family or society apart from the rest, subject only to its own internal laws. To attempt to count the stars in one of these globular clusters, he says, would be a vain task,—

that they are not to be reckoned by hundreds:—on a rough computation, it appears that many clusters of this description must contain ten or twenty thousand stars compacted and wedged together in a round space, whose area is not more than a tenth part of that covered by the moon; so that its center, where the stars are seen projected on each other, is one blaze of light (N. 225). If each of these stars be a sun, and if they be separated by intervals equal to that which separates our sun from the nearest fixed star, the distance which renders the whole cluster barely visible to the naked eye must be so great, that the existence of this splendid assemblage can only be known to us by light which must have left it at least a thousand years ago. Occasionally clusters are so irregular and so undefined in their outline as merely to suggest the idea of a richer part of the heavens. These contain fewer stars than the globular clusters, and sometimes a red star forms a conspicuous object among them. Sir William Herschel regarded them as the rudiments of globular clusters in a less advanced state of condensation, but tending to that form by their mutual attraction.

Multitudes of nebulous spots are to be seen on the clear vault of heaven, which have every appearance of being clusters like those described, but are too distant to be resolved into stars by the most excellent telescopes. Vast numbers also appear to be matter in the highest possible degree of rarefaction, giving no indication whatever of a stellar nature. These are in every state of condensation, from a vague film hardly to be discerned with telescopes of the highest powers, to such as seem to have actually arrived at a solid nucleus. This nebulous matter exists in vast abundance in space. No fewer than 2000 nebulæ and clusters of stars were observed by Sir William Herschel, whose places have been computed from his observations, reduced to a common epoch, and arranged into a catalogue in order of right ascension by his sister, Miss Caroline Herschel, a lady eminent for astronomical knowledge and discovery. Six or seven hundred nebulæ have already been ascertained in the southern hemisphere; of these the Magellanic clouds are the most remarkable. The nature

and use of this nebulous matter, scattered over the heavens in such a variety of forms, is involved in the greatest obscurity.   That it is a self-luminous, phosphorescent, material substance, in a highly dilated or gaseous state, but gradually subsiding by the mutual gravitation of its particles into stars and sidereal systems, is the hypothesis most generally received.   And indeed this is the hypothesis of La Place with regard to the origin of the solar system, which he conceived to be formed by the successive condensations of a nebula, whose primeval rotation is still maintained in the rotation and revolution of the sun and all the bodies of the solar system in the same direction.   Even at this day there is presumptive evidence in the structure and internal heat of the earth, of its having been at one period in a gaseous state from intensely high temperature. But the only way that any real knowledge on this mysterious subject can be obtained is by the determination of the form, place, and present state of each individual nebula; and a comparison of these with future observations will show generations to come the changes that may now be going on in these supposed rudiments of future systems.   With this view, Sir John Herschel began in the year 1825 the arduous and pious task of revising his illustrious father's observations, which he finished a short time before he sailed for the Cape of Good Hope, in order to disclose the mysteries of the southern hemisphere; indeed, our firmament seems to be exhausted till farther improvements in the telescope shall enable astronomers to penetrate deeper into space. In a truly splendid paper read before the Royal Society on the 21st of November, 1833, he gives the places of 2500 nebulæ and clusters of stars.   Of these 500 are new,—the rest he mentions with peculiar pleasure as having been most accurately determined by his father. This work is the more extraordinary, as from bad weather, fogs, twilight, and moonlight, these shadowy appearances are not visible, on an average, in England, above thirty nights in the year.

The nebulæ have great variety of forms.   Vast multitudes are so faint as to be with difficulty discerned at all till they have been for some time in the field of the

be hollow shells, only emitting light from their sur-
faces.

The existence of every degree of ellipticity in the
nebulæ—from long lenticular rays to the exact circular
form—and of every shade of central condensation—from
the slightest increase of density to apparently a solid
nucleus—may be accounted for by supposing the general
constitutions of these nebulæ to be that of oblate sphe-
roidal masses of every degree of flatness, from the
sphere to the disc, and of every variety in their density
and ellipticity toward the center. It would be errone-
ous, however, to imagine that the forms of these sys-
tems are maintained by forces identical with those
already described, which determine the form of a fluid
mass in rotation; because, if the nebulæ be only clus-
ters of separate stars, as in the greater number of cases
there is every reason to believe them to be, no pressure
can be propagated through them. Consequently, since
no general rotation of such a system as one mass can
be supposed, it may be conceived to be a quiescent form,
comprising within its limits an indefinite multitude of
stars, each of which may be moving in an orbit about
the common center of the whole, in virtue of a law of
internal gravitation resulting from the compound gravi-
tation of all its parts. Sir John Herschel has proved
that the existence of such a system is not inconsistent
with the law of gravitation under certain conditions.

The distribution of the nebulæ over the heavens is
even more irregular than that of the stars. In some
places they are so crowded together as scarcely to allow
one to pass through the field of the telescope before
another appears, while in other parts hours elapse with-
out a single nebula occurring. They are in general only
to be seen with the very best telescopes, and are most
abundant in a zone whose general direction is not far
from the hour circles 0^h and 12^h, and which crosses the
milky way nearly at right angles. Where that zone
crosses the constellations Virgo, Coma Berenices, and
the Great Bear, they are to be found in multitudes.

Such is a brief account of the discoveries contained
in Sir John Herschel's paper, which, for sublimity of
views and patient investigation, has not been surpassed.

To him and to Sir William Herschel we owe almost all that is known of sidereal astronomy : and in the inimitable works of that highly gifted father and son, the reader will find this subject treated of in a style altogether worthy of it, and of them.

Sir John Herschel has discovered some new and wonderful objects in the southern hemisphere. Among others a beautiful planetary nebula, having a perfectly sharp, well defined disc of uniform brightness, exactly like a small planet with a satellite near its edge. Another is mentioned as being very extraordinary from its blue tint : but by far the most singular is a close double star centrally involved in a nebulous atmosphere.

So numerous are the objects which meet our view in the heavens, that we cannot imagine a part of space where some light would not strike the eye ;—innumerable stars, thousands of double and multiple systems, clusters in one blaze with their tens of thousands of stars, and the nebulæ amazing us by the strangeness of their forms and the incomprehensibility of their nature, till at last, from the limit of our senses, even these thin and airy phantoms vanish in the distance. If such remote bodies shone by reflected light, we should be unconscious of their existence. Each star must then be a sun, and may be presumed to have its system of planets, satellites, and comets, like our own ; and, for aught we know, myriads of bodies may be wandering in space unseen by us, of whose nature we can form no idea, and still less of the part they perform in the economy of the universe. Even in our own system, or at its farthest limits, minute bodies may be revolving like the new planets, which are so small that their masses have hitherto been inappreciable, and there may be many still smaller. Nor is this an unwarranted presumption ; many such do come within the sphere of the earth's attraction, are ignited by the velocity with which they pass through the atmosphere, and are precipitated with great violence on the earth. The fall of meteoric stones is much more frequent than is generally believed. Hardly a year passes without some instances occurring ; and if it be considered that only a small part of the earth is inhabited, it may be presumed that numbers fall in

the ocean, or on the uninhabited part of the land, unseen by man. They are sometimes of great magnitude: the volume of several has exceeded that of the planet Ceres, which is about 70 miles in diameter. One which passed within 25 miles of us was estimated to weigh about 600,000 tons, and to move with a velocity of about 20 miles in a second—a fragment of it alone reached the earth. The obliquity of the descent of meteorites, the peculiar substances they are composed of, and the explosion accompanying their fall, show that they are foreign to our system. Luminous spots, altogether independent of the phases, have occasionally appeared on the dark part of the moon; these have been ascribed to the light arising from the eruption of volcanos; whence it has been supposed that meteorites have been projected from the moon by the impetus of volcanic eruption. It has even been computed, that if a stone were projected from the moon in a vertical line, with an initial velocity of 10,992 feet in a second—more than four times the velocity of a ball when first discharged from a cannon—instead of falling back to the moon by the attraction of gravity, it would come within the sphere of the earth's attraction, and revolve about it like a satellite. These bodies, impelled either by the direction of the primitive impulse, or by the disturbing action of the sun, might ultimately penetrate the earth's atmosphere, and arrive at its surface, but it is much more probable that they are asteroids revolving about the sun, and diverted from their course by some disturbing force; at all events, they must have a common origin, from the uniformity —we may almost say identity—of their chemical composition.

Shooting stars and meteors differ from aërolites in several respects. They burst from the clear azure sky, and darting along the heavens, are extinguished without leaving any residuum, except a vapor-like smoke, and generally without noise. Their parallax shows them to be very high in the atmosphere, sometimes even beyond its supposed limit, and the direction of their motion is for the most part diametrically opposite to the motion of the earth in its orbit. The astonishing multitudes of shooting stars and fire-balls that have appeared within

these few years at stated periods over the American continent, and other parts of the globe, warrant the conclusion that there is either a nebula, or that there are myriads of bodies revolving in groups round the sun which only become visible when inflamed by entering our atmosphere.

One of these nebulæ or groups seems to meet the earth in its annual revolution on the 12th and 13th of November.

On the morning of the 12th of November, 1799, thousands of shooting stars, mixed with large meteors, illuminated the heavens for many hours over the whole continent of America, from Brazil to Labrador : it extended to Greenland, and even Germany. Meteoric showers were seen off the coast of Spain, and in the Ohio country, on the morning of the 13th of November, 1831 ; and during many hours on the morning of the 13th November, 1832, prodigious multitudes of shooting stars and meteors fell at Mocha on the Red Sea, in the Atlantic, in Switzerland, and at many places in England. But by much the most splendid meteoric shower on record began at nine o'clock in the evening of the 12th of November, 1833, and lasted till sunrise next morning. It extended from Niagara and the northern lakes of America to the south of Jamaica, and from 61° of longitude in the Atlantic to 100° of longitude in central Mexico. Shooting stars and meteors, of the apparent size of Jupiter, Venus, and even the full moon, darted in myriads toward the horizon, as if every star in the heavens had started from their spheres. They are described as having been frequent as flakes of snow in a snow-storm, and to have been seen with equal brilliancy over the greater part of the continent of North America.

Those who witnessed this grand spectacle were surprised to see that every one of the luminous bodies, without exception, moved in lines which converged in one point in the heavens : none of them started from that point ; but their paths, when traced backward, met in it like rays in a focus, and the manner of their fall showed that they descended from it in nearly parallel straight lines toward the earth.

By far the most extraordinary part of the whole phenomenon is that this radiant point was observed to remain stationary near the star γ Leonis for more than two hours and a half, which proved the source of the meteoric shower to be altogether independent of the earth's rotation, and its parallax showed it to be far above the atmosphere.

As a body could not be actually at rest in that position, the group or nebula must either have been moving round the earth or the sun. Had it been moving about the earth, the course of the meteors would have been tangential to its surface, whereas they fell almost perpendicularly, so that the earth in its annual revolution must have met with the group. The bodies or the parts of the nebula that were nearest must have been attracted toward the earth by its gravity, and as they were estimated to move at the rate of fourteen miles in a second, they must have taken fire on entering our atmosphere, and been consumed in their passage through it.

As all the circumstances of the phenomenon were similar on the same day and during the same hours in 1832, and as extraordinary flights of shooting stars were seen at many places both in Europe and America on the 13th of November, 1834, 1835, and 1836, tending also from a fixed point in the constellation Leo, it has been conjectured, with much apparent probability, that this nebula or group of bodies performs its revolution round the sun in a period of about 182 days, in an elliptical orbit, whose major axis is 119 millions of miles; and that its aphelion distance, where it comes in contact with the earth's atmosphere, is about 95 millions of miles, or nearly the same with the mean distance of the earth from the sun. This body must have met with disturbances after 1799, which prevented it from encountering the earth for 32 years, and it may again deviate from its path from the same cause.

As early as the year 1833, Professor Olmsted, of Yale College in the United States of America, had conjectured that the phenomenon of shooting stars originated in the zodiacal light, and his subsequent observations, continued for three successive years, have tended

to confirm him in this opinion.   He agrees with La
Place in thinking that the zodiacal light is a nebulous
body, revolving in the plane of the solar equator.   In
fact, this light stretches beyond the earth's orbit, making
an angle of about 7¼° with the plane of the ecliptic, and
according to observation, it is sometimes seen in the
dawn, and sometimes in the twilight, like an inferior
planet.   It was seen by Professor Olmsted for several
weeks previous to the 13th of November, in the morn-
ing dawn, with an elongation (N. 231) of from 60° to
90° west of the sun.   It then by degrees withdrew from
the morning sky, and appeared in the evenings imme-
diately after twilight, rising like a pyramid through the
constellations Capricornus and Aquarius, to an elonga-
tion of more than 90° eastward of the sun.   A change
like this taking place annually about the 13th of Novem-
ber, has led the Professor to believe that it is to the
zodiacal light we are indebted for those splendid exhibi-
tions of falling stars which take place at that season.
   The orbit already described is that which he formerly
assigned to this nebulous or cometary body, but he is
now of opinion that it has a period of something less
than a year, which would not only account for the shoot-
ing stars of the 13th of November, but would also ac-
count for those that happen at all seasons, and for some
very great showers of them that have taken place on
two occasions near the end of April.   In the position
assigned to this orbit by Professor Olmsted, showers of
shooting stars may happen in November and April.
Since the last edition of this book a very able memoir
has been published by M. Biot, in which that great
philosopher shows that in his opinion also, meteoric
showers are owing to the zodiacal light coming into pe-
riodic contact with the atmosphere of the earth.   Which
of these conjectures may be nearest the truth time alone
can show ; but certain it is that the recurrence of this
phenomenon at the same season for seven successive
years proves that it can arise from no accidental cause.
    25   K K

SECTION XXXVIII.

Diffusion of Matter through Space—Gravitation—Its Velocity—Simplicity
of its Laws—Gravitation independent of the Magnitude and Distances of
the Bodies—Not impeded by the Intervention of any Substance—Its
Intensity invariable—General Laws—Recapitulation and Conclusion.

THE known quantity of matter bears a very small pro-
portion to the immensity of space. Large as the bodies
are, the distances which separate them are immeasura-
bly greater; but as design is manifest in every part of
creation, it is probable that if various systems in the
universe had been nearer to one another, their mutual
disturbances would have been consistent with the har-
mony and stability of the whole. It is clear that space
is not pervaded by atmospheric air, since its resistance
would, long ere this, have destroyed the velocity of the
planets; neither can we affirm it to be a void, since it
seems to be replete with ether, and traversed in all di-
rections by light, heat, gravitation, and possibly by influ-
ences whereof we can form no idea.

Whatever the laws may be that obtain in the more
distant regions of creation, we are assured that one alone
regulates the motions, not only of our own system, but
also of the binary systems of the fixed stars; and as
general laws form the ultimate object of philosophical re-
search, we cannot conclude these remarks without con-
sidering the nature of gravitation—that extraordinary
power, whose effects we have been endeavoring to trace
through some of their mazes. It was at one time im-
agined that the acceleration in the moon's mean motion
was occasioned by the successive transmission of the
gravitating force. It has been proved, that in order to
produce this effect, its velocity must be about fifty mill-
ions of times greater than that of light, which flies at
the rate of 200,000 miles in a second. Its action, even
at the distance of the sun, may therefore be regarded
as instantaneous; yet so remote are the nearest of the
fixed stars, that it may be doubted whether the sun has
any sensible influence on them.

The curves in which the celestial bodies move by the

force of gravitation are only lines of the second order. The attraction of spheroids, according to any other law of force than that of gravitation, would be much more complicated ; and as it is easy to prove that matter might have been moved according to an infinite variety of laws, it may be concluded that gravitation must have been selected by Divine Wisdom out of an infinity of others, as being the most simple, and that which gives the greatest stability to the celestial motions.

It is a singular result of the simplicity of the laws of nature, which admit only of the observation and comparison of ratios, that the gravitation and theory of the motions of the celestial bodies are independent of their absolute magnitudes and distances.   Consequently, if all the bodies of the solar system, their mutual distances, and their velocities, were to diminish proportionally, they would describe curves in all respects similar to those in which they now move ; and the system might be successively reduced to the smallest sensible dimensions, and still exhibit the same appearances.   We learn by experience that a very different law of attraction prevails when the particles of matter are placed within inappreciable distances from each other, as in chemical and capillary attraction, the attraction of cohesion, and molecular repulsion, yet it has been shown that in all probability not only these, but even gravitation itself, is only a particular case of the still more general principle of electric action.

The action of the gravitating force is not impeded by the intervention even of the densest substances.   If the attraction of the sun for the center of the earth, and of the hemisphere diametrically opposite to him, were diminished by a difficulty in penetrating the interposed matter, the tides would be more obviously affected.   Its attraction is the same also, whatever the substances of the celestial bodies may be ; for if the action of the sun upon the earth differed by a millionth part from his action upon the moon, the difference would occasion a periodical variation in the moon's parallax, whose maximum would be the $\frac{1}{15}$ of a second, and also a variation in her longitude amounting to several seconds, a supposition proved to be impossible, by the agreement of theory

with observation. Thus all matter is pervious to gravitation, and is equally attracted by it.

Gravitation is a feeble force, vastly inferior to electric action, chemical affinity, and cohesion; yet as far as human knowledge extends, the intensity of gravitation has never varied within the limits of the solar system; nor does even analogy lead us to expect that it should: on the contrary, there is every reason to be assured that the great laws of the universe are immutable, like their Author. Not only the sun and planets, but the minutest particles, in all the varieties of their attractions and repulsions,—nay, even the imponderable matter of the electric, galvanic, or magnetic fluid,—are all obedient to permanent laws, though we may not be able in every case to resolve their phenomena into general principles. Nor can we suppose the structure of the globe alone to be exempt from the universal fiat, though ages may pass before the changes it has undergone, or that are now in progress, can be referred to existing causes with the same certainty with which the motions of the planets, and all their periodic and secular variations, are referable to the law of gravitation. The traces of extreme antiquity perpetually occurring to the geologist give that information, as to the origin of things, in vain looked for in the other parts of the universe. They date the beginning of time with regard to our system; since there is ground to believe that the formation of the earth was contemporaneous with that of the rest of the planets; but they show that creation is the work of Him with whom "a thousand years are as one day, and one day as a thousand years."

In the work now brought to a conclusion, it has been necessary to select from the whole circle of the sciences a few of the most obvious of those proximate links which connect them together, and to pass over innumerable cases both of evident and occult alliance. Any one branch traced through its ramifications would alone have occupied a volume; it is hoped, nevertheless, that the view here given will suffice to show the extent to which a consideration of the reciprocal influence of even a few of these subjects may ultimately lead. It thus appears that the theory of dynamics, founded upon terrestrial

phenomena, is indispensable for acquiring a knowledge
of the revolutions of the celestial bodies and their recip-
rocal influences. The motions of the satellites are af-
fected by the forms of their primaries, and the figures
of the planets themselves depend upon their rotations.
The symmetry of their internal structure proves the
stability of these rotatory motions, and the immutability
of the length of the day, which furnishes an invariable
standard of time; and the actual size of the terrestrial
spheroid affords the means of ascertaining the dimensions
of the solar system, and provides an invariable founda-
tion for a system of weights and measures. The mutual
attraction of the celestial bodies disturbs the fluids at
their surfaces, whence the theory of the tides and of the
oscillations of the atmosphere. The density and elas-
ticity of the air, varying with every alternation of tem-
perature, lead to the consideration of barometrical
changes, the measurement of heights, and capillary at-
traction; and the doctrine of sound, including the theory
of music, is to be referred to the small undulations of
the aërial medium. A knowledge of the action of mat-
ter upon light is requisite for tracing the curved path of
its rays through the atmosphere, by which the true
places of distant objects are determined whether in the
heavens or on the earth. By this we learn the nature
and properties of the sunbeam, the mode of its propaga-
tion through the ethereal fluid, or in the interior of ma-
terial bodies, and the origin of color. By the eclipses of
Jupiter's satellites, the velocity of light is ascertained; and
that velocity, in the aberration of the fixed stars, fur-
nishes the only direct proof of the real motion of the
earth. The effects of the invisible rays of light are im-
mediately connected with chemical action; and heat,
forming a part of the solar ray so essential to animated
and inanimated existence, whether considered as invisi-
ble light or as a distinct quality, is too important an agent
in the economy of creation, not to hold a principal place
in the connection of physical sciences. Whence follows
its distribution in the interior and over the surface of the
globe, its power on the geological convulsions of our
planet, its influence on the atmosphere and on climate,
and its effects on vegetable and animal life, evinced in

of an orange, as in fig. 1; it is then called an oblate spheroid, because it
is flattened at the poles N and S. Such
is the form of the earth and planets.
When, on the contrary, it is drawn out
of the poles like an egg, as in fig. 2, it is
called a prolate spheroid. It is evident
that in both these solids the radii C q, C a,
C N, &c., are generally unequal; where-
as in the sphere they are all equal.

Fig. 2.

NOTE 10, p. 4.—*Center of gravity.* A
point in every body, which if supported,
the body will remain at rest in what-
ever position it may be placed. About
that point all the parts exactly balance
one another. The celestial bodies at-
tract each other as if each were con-
densed into a single particle situate in
the center of gravity, or the particle situ-
ate in the center of gravity of each may
be regarded as possessing the resultant
power of the innumerable oblique forces which constitute the whole
attraction of the body.

NOTE 11, pp. 4, 6.—*Poles and equator.* Let fig. 1 or 3 represent the
earth, C its center, N C S the axis of rotation, or the imaginary line about
which it performs its daily revolution. Then N and S are the north and
south poles, and the great circle q E Q, which divides the earth into two
equal parts, is the equator. The
earth is flattened at the poles fig.
1, the equatorial diameter, q Q,
exceeding the polar diameter, N S,
by about 26½ miles. Lesser cir-
cles, A B G, which are parallel to
the equator, are circles or parallels
of latitude, which is estimated in
degrees, minutes, and seconds,
north and south of the equator,
every place in the same parallel
having the same latitude: Green-
wich is in the parallel of 51°28′40″.
Thus terrestrial latitude is the an-
gular distance between the direc-
tion of a plumb-line at any place
and the plane of the equator.
Lines such as N Q S, N G E S,

Fig. 3.

fig. 3, are called meridians; all the places in any one of these lines have
noon at the same instant. The meridian of Greenwich has been chosen
by the British as the origin of terrestrial longitude, which is estimated in
degrees, minutes, and seconds, east and west of that line. If N G E S be
the meridian of Greenwich, the position of any place, B, is determined,
when its latitude, Q C B, and its longitude, E C Q, are known.

NOTE 12, p. 4.—*Mean quantities* are such as are intermediate between
others that are greater and less. The mean of any number of unequal
quantities is equal to their sum divided by their number. For instance,
the mean between two unequal quantities is equal to half their sum.

NOTE 13, p. 4.—*A certain mean latitude.* The attraction of a sphere on
an external body is the same as if its mass were collected into one heavy
particle in its center of gravity, and the intensity of its attraction dimin-
ishes as the square of its distance from the external body increases. But
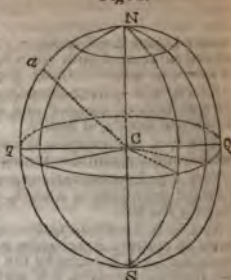
the attraction of a spheroid, fig. 1, on an external body at m in the plane of its equator, E Q, is greater, and its attraction on the same body when at m' in the axis N S less, than if it were a sphere. Therefore, in both cases, the force deviates from the exact law of gravity. This deviation arises from the protuberant matter at the equator; and as it diminishes toward the poles, so does the attractive force of the spheroid. But there is one mean latitude, where the attraction of a spheroid is the same as if it were a sphere. It is a part of the spheroid intermediate between the equator and the pole. In that latitude the square of the sine is equal to $\frac{1}{3}$ of the equatorial radius.

NOTE 14, p. 4.—*Mean distance.* The mean distance of a planet from the center of the sun, or of a satellite from the center of its planet, is equal to half the sum of its greatest and least distances, and consequently is equal to half the major axis of its orbit. For example, let P Q A D, fig. 6, be the orbit or path of the moon or of a planet; then P A is the major axis, C the center, and C S is equal to C F. Now, since the earth or the sun is supposed to be in the point S according as P D A Q is regarded as the orbit of the moon or that of a planet, S A, S P are the greatest and least distances. But half the sum of S A and S P is equal to half of A P, the major axis of the orbit. When the body is at Q or D, it is at its mean distance from S, for S Q, S D are each equal to C P, half the major axis by the nature of the curve.

NOTE 15, p. 4.—*Mean radius of the earth.* The distance from the center to the surface of the earth, regarded as a sphere. It is intermediate between the distances of the center of the earth from the pole and from the equator.

NOTE 16, p. 5.—*Ratio.* The relation which one quantity bears to another.

NOTE 17, p. 5.—*Square of moon's distance.* In order to avoid large numbers, the mean radius of the earth is taken for unity: then the mean distance of the moon is expressed by 60; and the square of that number is 3600, or 60 times 60.

NOTE 18, p. 5.—*Centrifugal force.* The force with which a revolving body tends to fly from the center of motion: a sling tends to fly from the hand in consequence of the centrifugal force. A tangent is a straight line touching a curved line in one point without cutting it, as m T, fig. 4. The direction of the centrifugal force is in the tangent to the curved line or path in which the body revolves, and its intensity increases with the angular swing of the body, and with its distance from the center of motion. As the orbit of the moon does not differ much from a circle, let it be represented by m d g h, fig. 4, the earth being in C. The centrifugal force arising from the velocity of the moon in her orbit balances the attraction of the earth. By their joint action, the moon moves through the arc m n during the time that she would fly off in the tangent m T by the action of the centrifugal force alone, or fall through m p by the earth's attraction alone. T n, the

Fig. 4.

deflection from the tangent, is parallel and equal to m p, the versed sine of the arc m n, supposed to be moved over by the moon in a second, and therefore so very small that it may be regarded as a straight line. T n,

ting a cone. A cone is a solid figure, like a sugar-loaf, fig. 5, of which A is the apex, A D the axis, and the plane B E C F the base. The axis may or .may not be perpendicular to the base, and the base may be a circle, or any other curved line. When the axis is perpendicular to the base, the solid is a right cone. If a right cone with a circular base be cut at right angles to the base by a plane passing through the apex, the section will be a triangle. If the cone be cut through both sides by a plane parallel to the base, the section will be a circle. If the cone be cut slanting quite through both sides, the section will be an ellipse, fig. 6. If the cone be cut parallel to one of the sloping sides, as A B, the section will be a parabola, fig. 7. And if the plane cut only one side of the cone, and be not parallel to the other, the section will be a hyperbola, fig. 8. Thus there are five conic sections.

NOTE 23, p. 5.—*Inverse square of distance.* The attraction of one body for another at the distance of two miles is four times less than at the distance of one mile ; at three miles, it is nine times less than at one ; at four miles, it is sixteen times less, and so on. That is, the gravitating force decreases in intensity as the squares of the distance increase.

NOTE 24, p. 5.—*Ellipse.* One of the conic sections, fig. 6. An ellipse may be drawn by fixing the ends of a string to two points, S and F, in a sheet of paper, and then carrying the point of a pencil round in the loop of the string kept stretched, the length of the string being greater than the distance between the two points. The points S and F are called the foci, C the center, S C or C F the eccentricity, A P the major axis, Q D the minor axis, and P S the focal distance. It is evident that the less the eccentricity C S, the nearer does the ellipse approach to a circle ; and from the construction it is clear that the length of the string S m F is equal to the major axis P A. If T t be a tangent to the ellipse at m, then the angle T m S is equal to the angle t m F ; and as this is true for every point in the ellipse, it follows, that in an elliptical reflecting surface, rays of light or sound coming from one focus S will be reflected by the surface to the other focus F, since the angle of incidence is equal to the angle of reflection by the theories of light and sound.

NOTE 25, p. 5.—*Periodic time.* The time in which a planet or comet performs a revolution round the sun, or a satellite about its planet.

NOTE 26, p. 5. Kepler discovered three laws in the planetary motions by which the principle of gravitation is established :—1st law, That the radii vectores of the planets and comets describe areas proportional to the time. Let fig. 9 be the orbit of a planet; then supposing the spaces or areas P S p, p S a, a S b, &c. equal to one another, the radius vector S P, which is the line joining the centers of the sun and planet, passes over these equal spaces in equal times, that is, if the line S P passes to S p in one day, it will come to S a in two days, to S b in three days, and so on. 2d law, That the orbits or paths of the planets and comets are conic sections, having the sun in one of their foci. The orbits of the planets and satellites are curves like fig. 6 or 9, called ellipses, having the sun in the focus S. Three comets are known to move in ellipses, but the greater part seem to move in parabolas, fig. 7, having the sun in S, though it is probable that they really move in very long flat ellipses; others appear to move in hyperbolas, like fig. 8. The third law is, that the squares of the periodic times of the planets are proportional to the cubes of their mean distances from the sun. The square of a number is that number multiplied by itself, and the cube of a num-

Fig. 9.
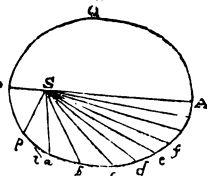
ber is that number twice multiplied by itself. For example, the squares of the numbers 2, 3, 4, &c. are 4, 9, 16, &c., but their cubes are 8, 27, 64, &c. Then the squares of the numbers representing the periodic times of two planets are to one another as the cubes of the numbers representing their mean distances from the sun. So that three of these quantities being known, the other may be found by the rule of three. The mean distances are measured in miles or terrestrial radii, and the periodic times are estimated in years, days, and parts of a day. Kepler's laws extend to the satellites.

NOTE 27, p. 5.—*Mass.* The quantity of matter in a given bulk. It is proportional to the density and volume or bulk conjointly.

NOTE 28, p. 5.—*Gravitation proportional to mass.* But for the resistance of the air, all bodies would fall to the ground in equal times. In fact a hundred equal particles of matter at equal distances from the surface of the earth would fall to the ground in parallel straight lines with equal rapidity, and no change whatever would take place in the circumstances of their descent, if 99 of them were united in one solid mass; for the solid mass and the single particle would touch the ground at the same instant, were it not for the resistance of the air.

NOTE 29, p. 5.—*Primary* signifies, in astronomy, the planet about which a satellite revolves. The earth is primary to the moon.

NOTE 30, p. 6.—*Rotation.* Motion round an axis, real or imaginary.

NOTE 31, p. 7.—*Compression of a spheroid.* The flattening at the poles. It is equal to the difference between the greatest and least diameters, divided by the greatest; these quantities being expressed in some standard measure, as miles.

NOTE 32, p. 7.—*Satellites.* Small bodies revolving about some of the planets. The moon is a satellite to the earth.

NOTE 33, p. 7.—*Nutation.* A nodding motion in the earth's axis while in rotation, similar to that observed in the spinning of a top. It is produced by the attraction of the sun and moon on the protuberant matter at the terrestrial equator.

NOTE 34, p. 7.—*Axis of Rotation.* The line, real or imaginary, about which a body revolves. The axis of the earth's rotation is that diameter, or imaginary line, passing through the center and both poles. Fig. 1 being the earth, N S is the axis of rotation.

NOTE 35, p. 7.—*Nutation of lunar orbit.* The action of the bulging matter at the earth's equator on the moon occasions a variation in the inclination of the lunar orbit to the plane of the ecliptic. Suppose the plane N p n, fig. 13, to be the orbit of the moon, and N m n the plane of the ecliptic, the earth's action on the moon causes the angle p N m to become less or greater than its mean state. The nutation in the lunar orbit is the reaction of the nutation in the earth's axis.

NOTE 36, p. 7.—*Translated.* Carried forward in space.

NOTE 37, p. 8.—*Force proportional to velocity.* Since a force is measured by its effect, the motions of the bodies of the solar system among themselves would be the same whether the system be at rest or not. The real motion of a person walking the deck of a ship at sea is compounded of his own motion and that of the ship, yet each takes place independently of the other. We walk about as if the earth were at rest, though it has the double motion of rotation on its axis and revolution round the sun.

NOTE 38, p. 8.—*Tangent.* A straight line which touches a curved line in one point without cutting it. In fig. 4, m T is tangent to the curve in the point m. In a circle the tangent is at right angles to the radius C m.

NOTE 39, p. 8.—*Motion in an elliptical orbit.* A planet m, fig. 6, moves round the sun at S in an ellipse P D A Q, in consequence of two forces

one urging it in the direction of the tangent *m* T, and another pulling it toward the sun in the direction *m* S. Its velocity, which is greatest at P, decreases throughout the arc to P D A to A, where it is least, and increases continually as it moves along the arc A Q P till it comes to P again. The whole force producing the elliptical motion varies inversely as the square of the distance. See Note 23.

NOTE 40, p. 8.—*Radii vectores.* Imaginary lines joining the center of the sun and the center of a planet or comet, or the centers of a planet and its satellite. In the circle, the radii are all equal ; but in an ellipse, fig. 6, the radius vector S A is greater, and S P less than all the others. The radii vectores, S Q, S D, are equal to C A or C P, half the major axis P A, and consequently equal to the mean distance. A planet is at its mean distance from the sun when in the points Q and D.

NOTE 41, p. 8.—*Equal areas in equal times.* See Kepler's 1st law in Note 26, p. 5.

NOTE 42, p. 8.—*Major Axis.* The line P A, fig. 6 or 10.

NOTE 43, p. 9.—*If the planet de-scribed a circle, &c.* The motion of a planet about the sun, in a circle A B P, fig. 10, whose radius C A is equal to the planet's mean distance from him, would be equable, that is, its velocity, or speed, would always be the same. Whereas, if it moved in the ellipse A Q P, its speed would be continually vary-ing, by Note 39 ; but its motion is such, that the time elapsing be-tween its departure from P, and its return to that point again, would be the same, whether it moved in the circle or in the ellipse ; for these curves coincide in the points P & A.

Fig. 10.

NOTE 44, p. 9.—*True motion.* The motion of a body in its real orbit P D A Q, fig. 10.

NOTE 45, p. 9.—*Mean motion.* Equable motion in a circle P E A B, fig. 10, at the mean distance C P or C *m*, in the time that the body would accomplish a revolution in its elliptical orbit P D A Q.

NOTE 46, p. 9. — *The equi-nox.* Fig. 11 represents the celestial sphere, and C its center, where the earth is sup-posed to be. *q* ♈ Q ♎ is the equinoctial or great circle, traced in the starry heavens by an imaginary extension of the plane of the terrestrial equator, and E ♈ *e* ♎ is the ecliptic, or apparent path of the sun round the earth. ♈ ♎, the intersection of these two planes, is the line of the equi-noxes ; ♈ is the vernal equi-nox, and ♎ the autumnal. When the sun is in these points, the days and nights are equal. They are distant from one another by a semi-

Fig. 11.

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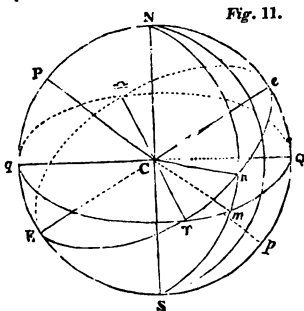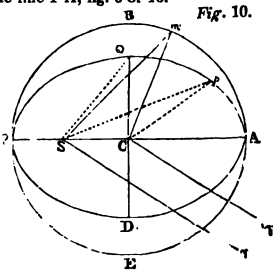
circle, or two right angles. The points E and e are the solstices, where the sun is at his greatest distance from the equinoctial. The equinoctial is everywhere ninety degrees distant from its poles N and S, which are two points diametrically opposite to one another, where the axis of the earth's rotation, if prolonged, would meet the heavens. The northern celestial pole N is within 1° 24′ of the pole star. As the latitude of any place on the surface of the earth is equal to the height of the pole above the horizon, it is easily determined by observation. The ecliptic E ϒ e ≏ is also everywhere ninety degrees distant from its poles P and p. The angle P C N, between the poles P and N of the equinoctial and ecliptic, is equal to the angle e C Q, called the obliquity of the ecliptic.

Note 47, p. 9.—*Longitude.* The vernal equinox, ϒ, fig. 11, is the zero point in the heavens whence celestial longitudes, or the angular motions of the celestial bodies, are estimated from west to east, the direction in which they all revolve. The vernal equinox is generally called the first point of Aries, though these two points have not coincided since the early ages of astronomy, about 2233 years ago, on account of a motion in the equinoctial points, to be explained hereafter. If S ϒ, fig. 10, be the line of the equinoxes, and ϒ the vernal equinox, the true longitude of a planet p is the angle ϒ S p, and its mean longitude is the angle ϒ C m, the sun being in S. Celestial longitude is the angular distance of a heavenly body from the vernal equinox ; whereas terrestrial longitude is the angular distance of a place on the surface of the earth from a meridian arbitrarily chosen, as that of Greenwich.

Note 48, pp. 9, 57.—*Equation of the center.* The difference between ϒ C m and ϒ S p, fig. 10 ; that is, the difference between the true and mean longitudes of a planet or satellite. The true and mean places only coincide in the points P and A ; in every other point of the orbit, the true place is either before or behind the mean place. In moving from A through the arc A Q P, the true place p is behind the mean place m ; and through the arc P D A the true place is before the mean place. At its maximum, the equation of the center measures C S, the eccentricity of the orbit, since it is the difference between the motion of a body in an ellipse and in a circle whose diameter A P is the major axis of the ellipse.

Note 49, p. 9.—*Apsides.* The points P and A, fig. 10, at the extremities of the major axis of an orbit. P is commonly called the perihelion, a Greek term, signifying *round the sun ;* and the point A is called the aphelion, a Greek term, signifying *at a distance from the sun.*

Note 50, p. 9.—*Ninety degrees.* A circle is divided into 360 equal parts, or degrees ; each degree into 60 equal parts, called minutes ; and each minute into 60 equal parts, called seconds. It is usual to write these quantities thus, 15° 16′ 10″, which means fifteen degrees, sixteen minutes, and ten seconds. It is clear that an arc m n, fig. 4, measures the angle m C n ; hence we may say, an arc of so many degrees, or an angle of so many degrees: for if there be ten degrees in the angle m C n, there will be ten degrees in the arc m n. It is evident that there are 90° in a right angle, m C d, or quadrant, since it is the fourth part of 360°.

Note 51, p. 9.—*Quadratures.* A celestial body is said to be in quadrature when it is 90 degrees distant from the sun. For example, in fig. 14, if d be the sun, S the earth, and P the moon, then the moon is said to be in quadrature when she is in either of the points Q or D, because the angles Q S d and D S d, which measure her apparent distance from the sun, are right angles.

Note 52, p. 9.—*Eccentricity.* Deviation from circular form. In fig. 6, C S is the eccentricity of the orbit, P Q A D. The less C S, the more

nearly does the orbit or ellipse approach the circular form; and when C S is zero, the ellipse becomes a circle.

Note 53, p. 9.—*Inclination of an orbit.* Let S, fig. 12, be the center of the sun, P N A π, the orbit of a planet moving from west to east in the direction N p. Let E N m e π be the shadow or projection of the orbit on the plane of the ecliptic, then N S π is the intersection of these two planes, for the orbit rises above the plane of the ecliptic toward N p, and sinks below it at N P. The angle p N m, which these two planes make with one another, is the inclination of the orbit P N p A to the plane of the ecliptic.
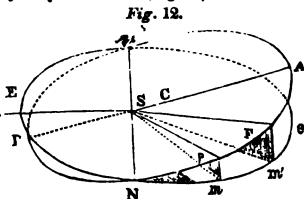
Fig. 12.

Note 54, p. 9.—*Latitude of a planet.* The angle p S m, fig. 12, or the height of the planet p above the ecliptic E N m. In this case the latitude is north. Thus, celestial latitude is the angular distance of a celestial body from the plane of the ecliptic, whereas terrestrial latitude is the angular distance of a place on the surface of the earth from the equator.

Note 55, p. 10.—*Nodes.* The two points N and π, fig. 12, in which the orbit N A π P of a planet or comet intersects the plane of the ecliptic e N E π. The part N A π of the orbit lies above the plane of the ecliptic, and the part π P N below it. The ascending node N is the point through which the body passes in rising above the plane of the ecliptic, and the descending node π is the point in which the body sinks below it. The nodes of a satellite's orbit are the points in which it intersects the plane of the orbit of the planet.

Note 56, p. 10.—*Distance from the sun.* S p in fig. 12. If ϒ be the vernal equinox, then ϒ S p is the longitude of the planet p, m S p is its latitude, and S p its distance from the sun. When these three quantities are known, the place of the planet p is determined in space.

Note 57, pp. 10, 58.—*Elements of an orbit.* Of these there are seven. Let P N A π, fig. 12, be the elliptical orbit of a planet, S the center, S the sun in one of the foci, ϒ the point of Aries, and E N e π the plane of the ecliptic. The elements are, the major axis A P; the eccentricity C S; the periodic time, that is, the time of a complete revolution of the body in its orbit; and the fourth is the longitude of the body at any given instant: for example, that at which it passes through the perihelion, P, the point of its orbit nearest to the sun. That instant is assumed as the origin of time, whence all preceding and succeeding periods are estimated. These four quantities are sufficient to determine the form of the orbit and the motion of the body in it. Three other elements are requisite for determining the position of the orbit in space. These are, the angle ϒ S P, the longitude of the perihelion; the angle A N e, which is the inclination of the orbit to the plane of the ecliptic; and lastly, the angle ϒ S N, the longitude of N the ascending node.

Note 58, p. 10.—*Whose planes, &c.* The planes of the orbits, as P N A π, fig. 12, in which the planets move, are inclined or make small angles e N A with the plane of the ecliptic E N e n, and cut it in straight lines, N S π passing through S the center of the sun.

Note 59, p. 12.—*Momentum.* Force measured by the weight of a body and its speed, or simple velocity, conjointly. The primitive momentum of the planets is, therefore, the quantity of motion which was impressed upon them when they were first thrown into space.

Note 60, p. 12.—*Unstable equilibrium.* A body is said to be in equili-

brium when it is so balanced as to remain at rest. But there are two
kinds of equilibrium, *stable* and *unstable*. If a body balanced in stable
equilibrium be slightly disturbed, it will endeavor to return to rest by a
number of movements to and fro, which will continually decrease till
they cease altogether, and then the body will be restored to its original
state of repose. But if the equilibrium be unstable, these movements to
and fro, or oscillations, will become greater and greater till the equili-
brium is destroyed.

NOTE 61, p. 13.—*Retrograde*. Going backward, as from east to west,
contrary to the motion of the planets.

NOTE 62, p. 14.—*Parallel directions*. Such as never meet, though
prolonged ever so far.

NOTE 63, pp. 14, 16.—*The whole force. &c.* Let S, fig. 13, be the sun,
N m n the plane of the ecliptic, p the dis-
turbed planet moving in its orbit n p N, and
d the disturbing planet. Now, d attracts the
sun and the planet p with different intensities
in the directions d S, d p: the difference only
of these forces disturbs the motion of p; it
is, therefore, called the disturbing force. But
this whole disturbing force may be regarded
as equivalent to three forces, acting in the
directions p S, p T, and p m. The force act-
ing in the radius vector p S, joining the cen-
ters of the sun and planet, is called the
radial force. It sometimes draws the dis-
turbed planet p from the sun, and sometimes
brings it nearer to him. The force which
acts in the direction of the tangent, p T,
is called the *tangential force*. It disturbs
the motion of p in longitude, that is, it accel-
erates its motion in some parts of its orbit
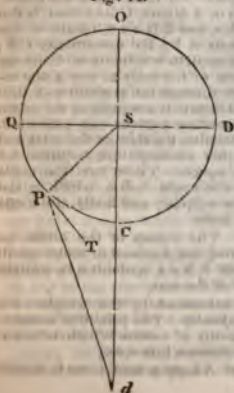
Fig. 13.

and retards it
in others, so
that the ra-
dius vector
S p does not
move over
equal areas
in equal times. (See Note 26.) For exam-
ple, in the position of the bodies in fig. 14,
it is evident that, in consequence of the
attraction of d, the planet P will have its
motion accelerated from Q to C, retarded
from C to D, again accelerated from D to
O, and, lastly, retarded from O to Q. The
disturbing body is here supposed to be at
rest, and the orbit circular; but as both
bodies are perpetually moving with dif-
ferent velocities in ellipses, the perturba-
tions or changes in the motions of P are
very numerous. Lastly, that part of the
disturbing force which acts in the direc-
tion of a line p m, fig. 13, at right angles
to the plane of the orbit N p n, may be
called the perpendicular force. It some-
times causes the body to approach nearer,
and sometimes to recede farther from, the

Fig. 14.

plane of the ecliptic, N *m n*, than it would otherwise do. The action of the disturbing forces is admirably explained in a work on gravitation, by Professor Airy, of Cambridge.

NOTE 64, pp. 16, 69.—*Perihelion.* Fig. 10, P, the point of an orbit nearest the sun.

NOTE 65, p. 16.—*Aphelion.* Fig. 10, A, the point of an orbit farthest from the sun.

NOTE 66, pp. 16, *ib.*, 17. In fig. 15 the central force is greater than the exact law of gravity; therefore the curvature P *p a* is greater than P *p* A the real ellipse; hence the planet *p* comes to the point *a*, called the aphelion, sooner than if it moved in the orbit P *p* A, which makes the line P S A advance to *a*. In fig. 16, on the contrary, the curvature P *p a* is

Fig. 15.   *Fig.* 16.
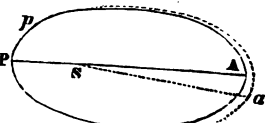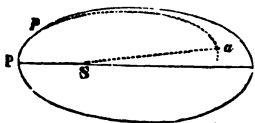
less than in the true ellipse, so that the planet *p* must move through more than the arc P *p* A, or 180°, before it comes to the aphelion *a*, which causes the greater axis P S A to recede to *a*.

NOTE 67, pp. 16, 17.—*Motion of apsides.* Let P S A, fig. 17, be the position of the elliptical orbit of a planet at any time; then, by the action of the disturbing forces, it successively takes the position P′ S A′, P″ S A″, &c., till by this direct motion it has accomplished a revolution, and then it begins again; so that the motion is perpetual.

Fig. 17.
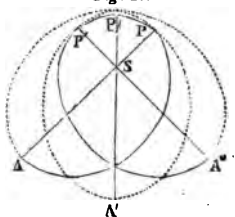
NOTE 68, p. 16.—*Sidereal revolution.* The consecutive return of an object to the same star.

NOTE 69, p. 16.—*Tropical revolution.* The consecutive return of an object to the same tropic or equinox.

NOTE 70, p. 17.—*The orbit only bulges, &c.* In fig. 18 the effect of the variation in the eccentricity is shown, where P *p* A is the elliptical orbit at any given instant; after a time it will take the form P *p′* A, in consequence of the decrease in the eccentricity C S; then the forms P *p″* A, P *p‴* A, &c., consecutively from the same cause, and as the major axis P A always retains the same length, the orbit approaches more and more nearly to the circular form. But after this has gone on for some thousands of years, the orbit contracts again, and becomes more and more elliptical.

Fig. 18.

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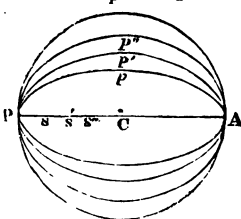
NOTE 71, pp. 18, 19.—*The ecliptic* is the apparent path of the sun in the heavens. See Note 46.

NOTE 72, p. 18.—*This force tends to pull, &c.* The force in question acting in the direction *p m*, fig. 13, pulls the planet *p* toward the plane N *m n*, or pushes it farther above it, giving the planet a tendency to move in an orbit above or below its undisturbed orbit N *p n*, which alters the angle *p* N *m*, and makes the node N and the line of nodes N *n* change their positions.

NOTE 73, p. 18.—*Motion of the nodes.* Let S, fig. 19, be the sun ; S N *n* the plane of the ecliptic ; P the disturbing body ; and *p* a planet moving in its orbit *p n*, of which *p n* is so small a part that it is represented as a straight line. The plane S *n p* of this orbit cuts the plane of the ecliptic in the straight line S *n*. Suppose the disturbing force begins to act on *p* so as to draw the planet into the arc *p p'* ; then, instead of moving in the orbit *p n*, it will tend to move in the orbit *p p' n'*, whose plane cuts the ecliptic in the straight line S *n*. If the disturbing force acts again upon the body when at *p'*, so as to draw it into the arc *p' p''*, the planet will now tend to move in the orbit *p' p'' n''*, whose plane cuts the ecliptic in the straight line S *n''*. The action of the disturbing force on the planet when at *p''*, will bring the node to *n'''*, and so on. In this manner the node goes backward through the successive points, *n, n', n'', n'''*, &c., and the line of nodes S *n* has a perpetual retrograde motion about

Fig. 19.
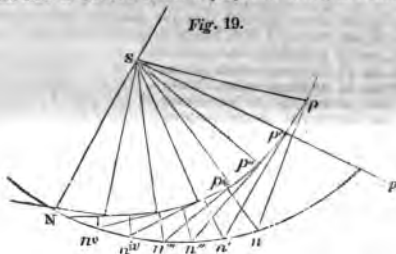
S, the center of the sun. The disturbing force has been represented as acting at intervals for the sake of illustration : in nature it is continuous, so that the motion of the node is continuous also ; though it is sometimes rapid and sometimes slow, now retrograde and now direct ; but on the whole, the motion is slowly retrograde.

NOTE 74, p. 18.— *When the disturbing planet* is anywhere in the line S N, fig. 19, or in its prolongation, it is in the same plane with the disturbed planet ; and however much it may affect its motions in that plane, it can have no tendency to draw it out of it. But when the disturbing planet is in P, at right angles to the line S N, and not in the plane of the orbit, it has a powerful effect on the motion of the nodes : between these two positions there is great variety of action.

NOTE 75, p. 19.— *The changes in the inclination* are extremely minute when compared with the motion of the node, as evidently appears from fig. 19, where the angles *n p n', n' p' n''*, &c. are much smaller than the corresponding angles *n* S *n', S n''*, &c.

NOTE 76, p. 20.—*Sines and cosines.* Figure 4 is a circle ; *n p* is the sine, and C *p* is the cosine of an arc *m n*. Suppose the radius C *m* to begin to revolve at *m*, in the direction *m n a* ; then at the point *m* the sine is zero, and the cosine is equal to the radius C *m*. As the line C *m*

revolves and takes the successive positions C n, C a, C b, &c., the sines
n p, a q, b r, &c. of the arcs m n, m a, m h, &c. increase, while the corres
ponding cosines C p, C q, C r, &c. decrease, and when the revolving radius
takes the position C d, at right angles to the diameter g m, the sine be-
comes equal to the radius C d, and the cosine is zero. After passing the
point d, the contrary happens; for the sines e K, l V, &c. diminish, and
the cosines C K, C V, &c. go on increasing, till at g the sine is zero, and
the cosine is equal to the radius C g. The same alternation takes place
through the remaining parts g h, h m, of the circle, so that a sine or cosine
never can exceed the radius. As the rotation of the earth is invariable,
each point of its surface passes through a complete circle, or 360 degrees,
in twenty-four hours, at a rate of 15 degrees in an hour. Time, there-
fore, becomes a measure of angular motion, and vice versâ, the arcs of a
circle a measure of time, since these two quantities vary simultaneously
and equably, and as the sines and cosines of the arcs are expressed in
terms of the time, they vary with it. Therefore, however long the time
may be, and how often soever the radius may revolve round the circle,
the sines and cosines never can exceed the radius; and as the radius is as-
sumed to be equal to unity, their values oscillate between unity and zero.

Note 77, p. 21.—The small eccentricities and inclinations of the plan-
etary orbits, and the revolutions of all the bodies in the same direction,
were proved by Euler, La Grange, and La Place, to be conditions neces-
sary for the stability of the solar system. Recently, however, the peri-
odicity of the terms of the series expressing the perturbations was sup-
posed to be sufficient *alone*, but M. Poisson has shown that to be a mistake ;
that these three conditions are requisite for the necessary convergence
of the series, and that therefore the stability of the system depends on
them *conjointly* with the periodicity of the sines and cosines of each
term. The author is aware that this note can only be intelligible to the
analyst, but she is desirous of correcting an error, and the more so as the
conditions of stability afford one of the most striking instances of design
in the original construction of our system, and of the foresight and su-
preme wisdom of the Divine Architect.

Note 78, p. 21.—*Resisting medium.* A fluid which resists the motions
of bodies such as atmospheric air, or the highly elastic fluid called ether,
with which it is presumed that space is filled.

Note 79, p. 22.—*Obliquity of the ecliptic.* The angle e ♈ q, fig. 11, be-
tween the plane of the terrestrial equator q ♈ Q, and the plane of the eclip
tic E ♈ e. The obliquity is variable.

Note 80, p. 22.—*Invariable plane.* In the earth the equator is the in-
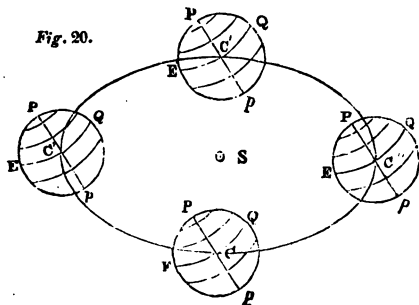
Fig. 20.

variable plane which nearly maintains a parallel position with regard to itself while revolving about the sun, as in fig. 20, where E Q represents it. The two hemispheres balance one another on each side of this plane, and would still do so if all the particles of which they consist were moveable among themselves, provided the earth were not disturbed by the action of the sun and moon, which alters the parallelism of the equator by the small variation called nutation, to be explained hereafter.

NOTE 81, p. 23. *If each particle, &c.* Let P, P′, P″, &c., fig. 21, be planets moving in their orbits about the center of gravity of the system.

Fig. 21.
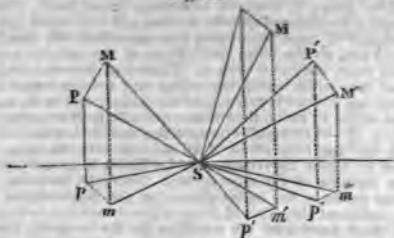
Let P S M, P′ S M′, &c. be portions of these orbits moved over by the radii vectores, S P, S P′, &c., in a given time, and let p S m, p′ S m′ &c. be their shadows or projections on the invariable plane. Then, if the numbers which represent the masses of the planets, P, P′ &c. be respectively multiplied by the numbers representing the areas or spaces p S m, p′ S m′, &c. the sum of the whole will be greater for the invariable plane than it would be for any plane that could pass through S, the center of gravity of the system.

NOTE 82, p. 23.— *The center of gravity* of the solar system lies within the body of the sun, because his mass is much greater than the masses of all the planets and satellites added together.

NOTE 83, pp. 24, 35.— *Conjunction.* A planet is said to be in conjunction when it has the same longitude with the sun, and in opposition when its longitude differs from that of the sun by 180 degrees. Thus two bodies are said to be in conjunction when they are seen exactly in the same part of the heavens, and in opposition when diametrically opposite to one another. Mercury and Venus, which are nearer to the sun than the earth, are called inferior planets, while all the others, being farther from the sun than the earth, are said to be superior planets. Suppose the earth to be at E, figure 24 ; then a superior planet will be in conjunction with the sun at C, and in opposition to him when at O. Again, suppose the earth to be in O, then an inferior planet will be in conjunction when at E, and in opposition when at F.

NOTE 84, p. 25.— *The periodic inequalities* are computed for a given time ; and consequently for a given form and position of the orbits of the disturbed and disturbing bodies. Although the elements of the orbits vary so slowly that no sensible effect is produced on inequalities of a short period ; yet, in the course of time, the secular variations of the elements change the forms and relative positions of the orbits so much, that Jupiter and Saturn, which would have come to the same relative positions with regard to the sun and to one another after 850 years, do not arrive *at the same relative* positions till after 918 years.

NOTE 85, p. 25.—*Configuration.* The relative position of the planets with regard to one another, to the sun, and to the plane of the ecliptic.

NOTE 86, p. 26.—In the same manner that the eccentricity of an elliptical orbit may be increased or diminished by the action of the disturbing forces, so a circular orbit may acquire less or more ellipticity from the same cause. It is thus that the forms of the orbit of the first and second satellites of Jupiter oscillate between circles and ellipses differing very little from circles.

NOTE 87, p. 27.—*The plane of Jupiter's equator* is the imaginary plane passing through his center at right angles to his axis of rotation ; and corresponds to the plane *q* E Q *e*, in fig. 1. The satellites move very nearly in the plane of Jupiter's equator, for if J be Jupiter, fig. 22, P *p* his

Fig. 22.
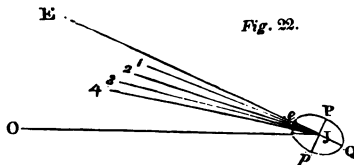
axis of rotation, *e* Q his equatorial diameter, which is 6000 miles longer than P *p*, and if J O and J E be the planes of his orbit and equator seen edgewise, then the orbits of his four satellites seen edgewise will have the positions J 1, J 2, J 3, J 4. These are extremely near to one another, for the angle E J O is only 3° 5′ 30″.

NOTE 88, p. 27.—In consequence of the satellites moving so nearly in the plane of Jupiter's equator, when seen from the earth, they appear to be always very nearly in a straight line, however much they may change their positions with regard to one another and to their primary. For example, on the evenings of the 3d, 4th, 5th, and 6th of January, 1835, the satellites had the configurations given in fig. 23, where O is Jupiter,

Fig. 23.

and 1, 2, 3, 4, are the first, second, third, and fourth satellites. The satellite is supposed to be moving in a direction from the figure toward the point. On the sixth evening the second satellite was seen on the disc of the planet.

NOTE 89, p. 28.—*Angular motion or velocity* is the swiftness with which a body revolves—a sling, for example ; or the speed with which the surface of the earth performs its daily rotation about its axis.

NOTE 90, p. 28.—*Displacement of Jupiter's orbit.* The action of the planets occasions secular variations in the position of Jupiter's orbit, J O, fig. 22, without affecting the plane of his equator, J E. Again, the sun and satellites themselves, by attracting the protuberant matter at Jupiter's equator, change the position of the plane J E without affecting J O. Both of these cause perturbations in the motions of the satellites.

NOTE 91, p. 28.—*Precession,* with regard to Jupiter, is a retrograde motion of the point where the lines J O, J E, intersect fig. 22.

NOTE 92, p. 29.—*Synodic motion of a satellite.* Its motion during the interval between two of its consecutive eclipses.

NOTE 93, p. 29.—*Opposition.* A body is said to be in opposition when its longitude differs from that of the sun by 180°. If S, fig. 24, be the

Fig. 24.
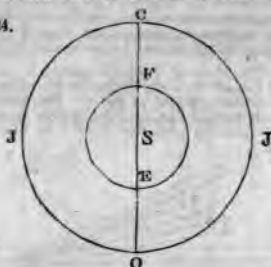
sun, and E the earth, then Jupiter is in opposition when at O, and in conjunction when at C. In these positions the three bodies are in the same straight line.

NOTE 94, p. 29.—*Eclipses of the satellites.* Let S, fig. 25, be the sun, J Jupiter, and a B b his shadow. Let the earth be moving in its orbit, in the direction E A R T H, and the third satellite in the direction a b m n. When the earth is at E, the satellite, in moving through the arc a b, will vanish at a, and reappear at b, on the same side of Jupiter. If the earth be in R, Jupiter will be in opposition; and then the satellite, in moving through the arc a b, will vanish close to the disc of the planet, and will reappear on the other side of it. But if the satellite be moving through the arc m n, it will appear to pass over the disc and eclipse the planet.

Fig. 25.
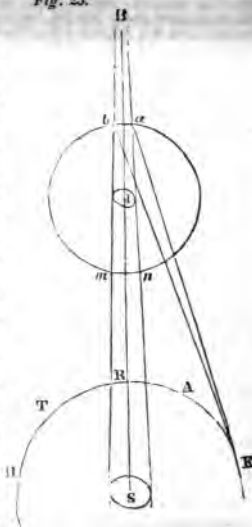
NOTE 95, pp. 30, 42.—*Meridian.* A terrestrial meridian is a line passing round the earth and through both poles. In every part of it noon happens at the same instant. In figures 1 and 3, the lines N Q S and N G S are meridians, C being the center of the earth, and N S its axis of rotation. The meridian passing through the Observatory at Greenwich is assumed by the British as a fixed origin from whence terrestrial longitudes are measured. And as each point on the surface of the earth passes through 360°, or a complete circle in twenty-four

hours, at the rate of 15 degrees in an hour, time becomes a representative of angular motion. Hence if the eclipse of a satellite happens at any place at eight o'clock in the evening, and the Nautical Almanac shows that the same phenomenon will take place at Greenwich at nine, the place of observation will be in the 15° of west longitude.

NOTE 96, p. 30.—*Conjunction.* Let S be the sun, fig. 24, E the earth, and J O J' C' the orbit of Jupiter. Then the eclipses which happen when Jupiter is in O are seen 16^m 26^s sooner than those which take place when the planet is in C. Jupiter is in conjunction when at C and in opposition when in O.·

NOTE 97, p. 30.—*In the diagonal, &c.* Were the line A S, fig. 26, 100,000 times longer than A B, Jupiter's true place would be in the direction A S', the diagonal of the figure A B S' S, which is, of course, out of proportion.

Fig. 26.
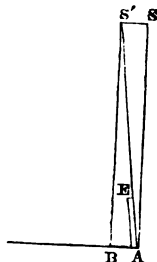
NOTE 98, p. 31.—*Aberration of light.* The celestial bodies are so distant, that the rays of light coming from them may be reckoned parallel. Therefore, let S A, S' B, fig. 26, be two rays of light coming from the sun, or a planet, to the earth moving in its orbit in the direction A B. If a telescope be held in the direction A S, the ray S A, instead of going down the tube, will impinge on its side, and be lost in consequence of the telescope being carried with the earth in the direction A B. But if the tube be held in the position A E, so that A B is to A S as the velocity of the earth to the velocity of light, the ray will pass through S' E A. The star appears to be in the direction A S, when it really is in the direction A S', hence the angle S A S' is the angle of aberration.

NOTE 99, p. 31.—*Density proportional to elasticity.* The more a fluid, such as atmospheric air, is reduced in dimensions by pressure, the more it resists the pressure.

NOTE 100, p. 32.—*Oscillations of pendulum retarded.* If a clock be carried from the pole to the equator, its rate will be gradually diminished, that is, it will go slower and slower, because the centrifugal force which increases from the pole to the equator, diminishes the force of gravity.

NOTE 101, p. 33.—*Disturbing action.* The disturbing force acts here in the very same manner as in note 63; only that the disturbing body d, fig. 14, is the sun, S the earth, and p the moon.

NOTE 102, pp. 34, 36, 81.—*Perigee.* A Greek word signifying round the earth. The perigee of the lunar orbit is the point P, fig. 6, where the moon is nearest to the earth. It corresponds to the perihelion of a planet. Sometimes the word is used to denote the point where the sun is nearest to the earth.

NOTE 103, p. 34.—*Evection.* The evection is produced by the action of the radial force in the direction S p, fig. 14, which sometimes increases and sometimes diminishes the earth's attraction to the moon. It produces a corresponding temporary change in the eccentricity, which varies with the position of the major axis of the lunar orbit in respect of the line S d, joining the centers of the earth and sun.

NOTE 104, p. 34.—*Variation.* The lunar perturbation called the variation is the alternate acceleration and retardation of the moon in longitude, from the action of the tangential force. She is accelerated in going from quadratures in Q and D, fig. 14, to the points C and O, called syzygies, and is retarded in going from the syzygies C and O to Q and D again.

parallel of latitude, A *a*, B G; therefore a change in the parallax observed in that parallel can only arise from a change in the moon's distance from the earth: and when the moon is at her mean distance, which is a constant quantity equal to half the major axis of her orbit, a change in the parallax observed in different latitudes, G and E, must arise from the difference in the lengths of the radii *n* G and C E.

NOTE 130, p. 52.—*When Venus is in her nodes.* She must be in the line N S *n*, where her orbit P N A *n* cuts the plane of the ecliptic E N *e n*, fig. 12.

NOTE 131, p. 52.—*The line described, &c.* Let E, fig. 33, be the earth,

Fig. 33.

S the center of the sun, and V the planet Venus. The real transit of the planet, seen from E the center of the earth, would be in the direction A B. A person at W would see it pass over the sun in the line *v a*, and a person at O would see it move across him in the direction *v' a'*.

NOTE 132, p. 53.—*Kepler's law.* Suppose it were required to find the distance of Jupiter from the sun. The periodic times of Jupiter and Venus are given by observation, and the mean distance of Venus from the center of the sun is known in miles or terrestrial radii: therefore, by the rule of three, the square root of the periodic time of Venus is to the square root of the periodic time of Jupiter, as the cube root of the mean distance of Venus from the sun, to the cube root of the mean distance of Jupiter from the sun, which is thus obtained in miles or terrestrial radii. The root of a number is that number which, once multiplied by itself, gives its square; twice multiplied by itself, gives its cube, &c. For example, twice 2 are 4, and twice 4 are 8; 2 is therefore the square root of 4, and the cube root of 8. In the same manner 3 times 3 are 9, and 3 times 9 are 27; 3 is therefore the square root of 9, and the cube root of 27.

NOTE 133, p. 55.—*Inversely, &c.* The quantities of matter in any two primary planets are greater in proportion as the cubes of the numbers representing the mean distances of their satellites are greater, and also in proportion as the squares of their periodic times are less.

NOTE 134, p. 55.—As hardly anything appears more impossible than that man should have been able to weigh the sun as it were in scales and the earth in a balance, the method of doing so may have some interest. The attraction of the sun is to the attraction of the earth, as the quantity of matter in the sun to the quantity of matter in the earth: and as the force of this reciprocal attraction is measured by its effects, the space the earth would fall through in a second by the sun's attraction, is to the space which the sun would fall through by the earth's attraction, as the mass of the sun to the mass of the earth. Hence, as many times as the fall of the earth to the sun in a second exceeds the fall of the sun to the earth in the same time, so many times does the mass of the sun exceed the mass of the earth. Thus the weight of the sun will be known if the length of these two spaces can be found in miles or parts of a mile. Nothing can be easier. A heavy body falls through 16·0697 feet in a second at the surface of the earth by the earth's attraction; and as the force of gravity is inversely as the square

of the distance, it is clear that 16·0697 feet are to the space a body would fall through at the distance of the sun by the earth's attraction, as the square of the distance of the sun from the earth to the square of the distance of the center of the earth from its surface; that is, as the square of 95,000,000 miles to the square of 4000 miles. And thus, by a simple question in the rule of three, the space which the sun would fall through in a second by the attraction of the earth may be found in parts of a mile. The space the earth would fall through in a second by the attraction of the sun must now be found in miles also. Suppose m n, fig. 4, to be the arc which the earth describes round the sun in C in a second of time, by the joint action of the sun and the centrifugal force. By the centrifugal force alone the earth would move from m to T in a second, and by the sun's attraction alone it would fall through T n in the same time. Hence the length of T n in miles is the space the earth would fall through in a second by the sun's attraction. Now as the earth's orbit is very nearly a circle, if 360 degrees be divided by the number of seconds in a sidereal year of 365¼ days, it will give m n, the arc which the earth moves through in a second, and then the tables will give the length of the line T C in numbers corresponding to that angle; but as the radius C n is assumed to be unity in the tables, if 1 be subtracted from the number representing C T, the length of T n will be obtained; and when multiplied by 95,000,000 to reduce it to miles, the space which the earth falls through by the sun's attraction will be obtained in miles. By this simple process it is found that if the sun were placed in one scale of a balance, it would require 354,936 earths to form a counterpoise.

NOTE 135, p. 58. The sum of the greatest and least distances, S P, S A, fig. 12, is equal to P A, the major axis; and their difference is equal to twice the eccentricity C S. The longitude ♈ S P of the planet, when in the point P, at its least distance from the sun, is the longitude of the perihelion. The greatest height of the planet above the plane of the ecliptic E N e n is equal to the inclination of the orbit P N A n to that plane. The longitude of the planet, when in the plane of the ecliptic, can only be the longitude of one of the points N or n; and when one of these points is known, the other is given, being 180° distant from it. Lastly, the time included between two consecutive passages of the planet through the same node N or n is its periodic time, allowance being made for the recess of the node in the interval.

NOTE 136, p. 59. Suppose that it were required to find the position of a point in space, as of a planet, and that one observation places it in n, fig. 34, another observation places it in n', another in n'', and so on; all the points n, n', n'', n''', &c. being very near to one another. The true place of the planet P will not differ much from any of these positions. It is evident, from this view of the subject, that P n, P n', P n'', &c. are the errors of observation. The true position of the planet P is found by this property, that the squares of the numbers representing the lines P n, P n', &c., when added together, are the least possible.

Fig. 34.

Each line P n, P n', &c. being the whole error in the place of the planet, is made up of the errors of all the elements; and when compared with the errors obtained from theory, it affords the means of finding each. The principle of least squares is of very general application; its demonstration cannot find a place here; but the reader is referred to Biot's Astronomy, vol. ii. p. 203.
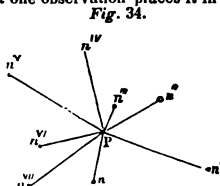
NOTE 137, p. 61.—*An axis that, &c.* Fig. 20 represents the earth

rate of 180° in twelve hours, which is the time included between the passages of the moon at the upper and under meridian.

Note 153, p. 99.—If S be the earth, fig. 14, *d* the sun, and C Q O D the orbit of the moon, then C and O are the syzygies. When the moon is new she is at C, and when full she is at O; and as both sun and moon are then on the same meridian, it occasions the spring-tides, it being high water at places under C and O, while it is low water at those under Q and D. The neap-tides happen when the moon is in quadrature at Q or D, for then she is distant from the sun by the angle *d* S Q, or *d* S D, each of which is 90°.

Note 154, pp. 89, 90.—*Declination.* If the earth be in C, fig. 11, and if *q* ♈ Q be the equinoctial, and N *m* S a meridian, then *m* C *n* is the declination of a body at *n*. Therefore the cosine of that angle is the cosine of the declination.

Note 155, p. 91.—*Moon s southing.* The time when the moon is on the meridian of any place, which happens about forty-eight minutes later every day.

Note 156, pp. 93, 124.—Fig. 37 shows the propagation of waves from

Fig. 37.

C· C¹
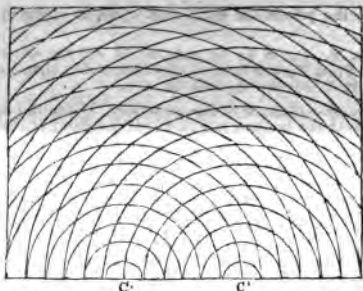
two points C and C′, where stones are supposed to have fallen. Those points in which the waves cross each other, are the places where they counteract each other's effects, so that the water is smooth there, while it is agitated in the intermediate spaces.

Note 157, p. 94.—*The centrifugal force may, &c.* The centrifugal force acts in a direction at right angles to N S, the axis of rotation, fig. 30. Its effects are equivalent to two forces, one of which is in the direction *b m* perpendicular to the surface Q *m n* of the earth, and diminishes the force of gravity at *m*. The other acts in the direction of the tangent *m* T, which makes the fluid particles tend toward the equator.

Note 158, p. 101.—*Analytical formula or expression.* A combination of symbols or signs expressing or representing a series of calculation, and including every particular case that can arise from a general law.

Note 159, p. 104.—*Platina.* The heaviest of metals; its color is between that of silver and lead.

Note 160, p. 105.—*Fig. 38 is a perfect octahedron.* Sometimes 'ts angles, Λ, X, *a, a,* &c., are truncated, or cut off. Sometimes a slice is cut

off its edges A a, X a, a a, &c. Occasionally both these modifications take place.

Fig. 38.
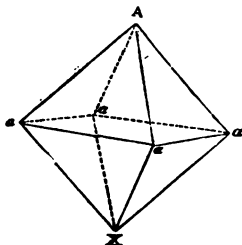
NOTE 161, p. 106. — Prismatic crystals of sulphate of nickel are some-what like fig. 62, only that they are thin, like a hair.

NOTE 162, p. 106. — Zinc, a metal either found as an ore or mixed with other metals. It is used in making brass.

NOTE 163, p. 107. — *A cube* is a solid contained by six plane square surfaces, as fig. 39.

Fig. 39.
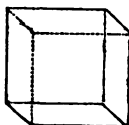
Fig. 40.
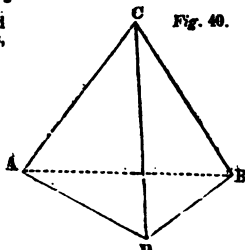
NOTE 164, p. 107. — *A tetrahedron* is a solid contained by four triangular surfaces, as fig. 40: of this solid there are many varieties.

NOTE 165, p. 107. — There are many varieties of the octahedron. In that mentioned in the text, the base a a a a, fig. 38, is a square, but the base may be a rhomb; this solid may also be elongated in the direction of its axis A X, or it may be depressed.

NOTE 166, pp. 108, 186. — *A rhombohedron* is a solid contained by six plane surfaces, as in fig. 63, the opposite planes being equal and similar rhombs parallel to one another; but all the planes are not necessarily equal or similar, nor are its angles right angles. In carbonate of lime the angle C A B is 105°·55, and the angle B or C is 75°·05.

NOTE 167, p. 108. — *Sublimation.* Bodies raised into vapor which is again condensed into a solid state.

NOTE 168, p. 109. — The surface of a column of water, or spirit of wine, in a capillary tube, is hollow; and that of a column of quicksilver is convex, or round-ed, as in fig. 41.

Fig. 41.

27
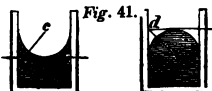
Note 169, p. 109.—*Inverse ratio, &c.* The elevation of the liquid is greater in proportion as the internal diameter of the tube is less.

Note 170, p. 110.—In fig. 41, the line *c d* shows the direction of the resulting force in the two cases.

Note 171, p. 110.—When two plates of glass are brought near to one another in water, the liquid rises between them; and if the plates touch each other at one of their upright edges, the outline of the water will become a hyperbola.

Note 172, p. 111.—Let A A', fig. 42, be two plates, both of which are wet, and B B', two that are dry. When partly immersed in a liquid, its

Fig. 42.
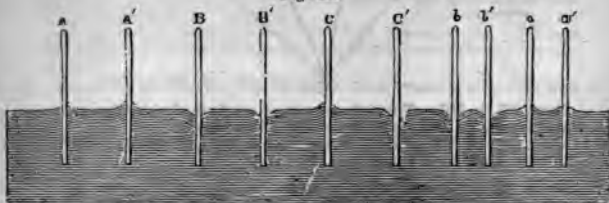
surface will be curved close to them, but will be of its usual level for the rest of the distance. At such a distance, they will neither attract nor repel one another. But as soon as they are brought near enough to have the whole of the liquid surface between them curved, as in *a a'*, *b b'*, they will rush together. If one be wet and another dry, as C C', they will repel one another at a certain distance; but as soon as they are brought very near, they will rush together, as in the former cases.

Note 173, p. 128.—*Latent heat.* There is a certain quantity of heat in all bodies, which cannot be detected by the thermometer, but which may become sensible by compression.

Note 174, p. 131.—*Reflected waves.* A series of waves of light, sound,
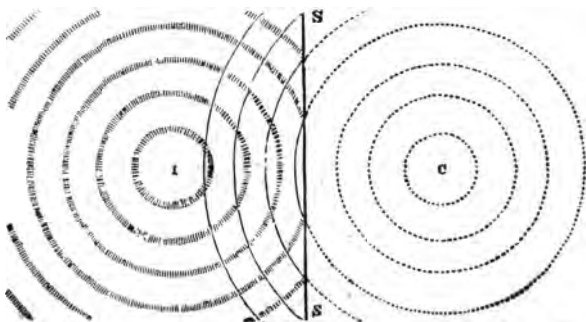
Fig. 43.

or water, diverge in all directions from their origin I, fig. 43, as from a center. When they meet with an obstacle S S, they strike against it, and are reflected or turned back by it in the same form, as if they had proceeded from the center C, at an equal distance on the other side of the surface S S.

NOTE 175, p. 132.—*Elliptical shell.* If fig. 6 be a section of an ellip-tical shell, then all sounds coming from the focus S to different points on the surface, as *m*, are reflected back to F, because the angle T *m* S is equal to *t m* F. In a spherical hollow shell, a sound diverging from the center is reflected back to the center again.

NOTE 176, p. 136. Fig. 44 represents musical strings in vibration; the

Fig. 44.
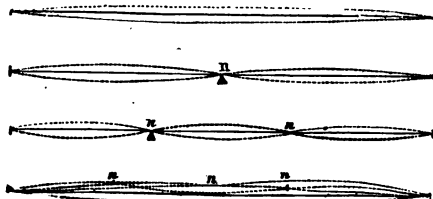
straight lines are the strings when at rest. The first figure of the four would give the fundamental note, as, for example, the low C. The second and third figures would give the first and second harmonics; that is, the octave and the 12th above C, *n n n* being the points of rest; the fourth figure shows the real motion when compounded of all three.

NOTE 177, p. 137. Fig. 45 represents sections of an open and of a shut pipe, and of a pipe open at one end. When sounded, the air sponta-neously divides itself into segments. It remains at rest in the divisions

Fig. 45
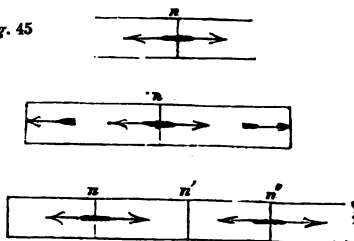
or nodes *n n'*, &c., but vibrates between them in the direction of the arrow-heads. The undulations of the whole column of air give the fundamental note, while the vibrations of the divisions give the har-monics.

NOTE 178, p. 139. Fig. 1, plate 1, shows the vibrating surface when the sand divides it into squares, and fig. 2 represents the same when the nodal lines divide it into triangles. The portions marked *a a* are in different states of vibration from those marked *b b*.

NOTE 179, p. 140. Plates 1 and 2 contain a few of Chladni's figures. The white lines are the forms assumed by the sand, from different modes of vibration, corresponding to musical notes of different degrees of pitch. Plate 3 contains six of Chladni's circular figures.

NOTE 180, p. 140. Mr. Wheatstone's principle is, that when vibrations producing the forms of figs. 1 and 2, plate 3, are united in the same surface, they make the sand assume the form of fig. 3. In the same manner, the vibrations which would separately cause the sand to take the forms of figs. 4 and 5, would make it assume the form of fig. 6 when united. The figure 9 results from the modes of vibration of 7 and 8 combined. The parts marked *a a* are in different states of vibration from those marked *b b*. Figs. 1, 2, and 3, plate 4, represent forms which the sand takes in consequence of simple modes of vibration; 4 and 5 are those arising from two combined modes of vibration; and the last six figures arise from four superimposed simple modes of vibration. These complicated figures are determined by computation independent of experiment.

NOTE 181, p. 140.—The long cross-lines of fig. 46 show the two systems of nodal lines given by M. Savart's laminæ.

[*Fig.* 46.
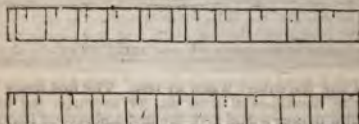
NOTE 182, p. 141.—The short lines on fig. 46 show the positions of the nodal lines on the other sides of the same laminæ.

NOTE 183, p. 141.—Fig. 47 gives the nodal lines on a cylinder, with the paper rings that mark the quiescent points.

Fig. 47.
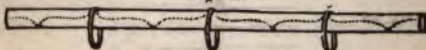
NOTE 184, pp. 133, 148, 149.—*Reflection and refraction.* Let P C *p*, fig. 48, be perpendicular to a surface of glass or water A B. When a ray of light, passing through the air, falls on this surface in any direction I C, part of it is reflected in the direction C S, and the other part is bent at C, and passes through the glass or water in the direction C R. I C is called the incident ray, and I C P the angle of incidence; C S is the reflected ray, and P C S the angle of reflection; C R is the refracted ray, and *p* C R the angle of refraction. The plane passing through S C and I C is the plane of reflection, and the plane passing through I C and C R is the plane of refraction. In ordinary cases, C I, C S, C R, are all

Fig. 48.

in the same plane. We see the surface by means of the reflected light, which would otherwise be invisible. Whatever the reflecting surface may be, and however obliquely the light may fall upon it, the angle of reflection is always equal to the angle of incidence. Thus I C, I′ C, being rays incident on the surface at C, they will be reflected into C S, C S′, so that the angle S C P will be equal to the angle I C P, and S′ C P equal to I′ C P. That is by no means the case with the refracted rays. The incident rays I C, I′ C, are bent at C, toward the perpendicular, in the direction C R, C R′; and the law of refraction is such, that the sine of the angle of incidence has a constant ratio to the sine of the angle of refraction; that is to say, the number expressing the length of I m, the sine of I C P, divided by the number expressing the length of R n, the sine of R C p, is the same for all the rays of light that can fall upon the surface of any one substance, and is called its Index of refraction. Though the index of refraction be the same for any one substance, it is not the same for all substances. For water it is 1·336; for crown-glass it is 1·535; for flint-glass, 1·6; for diamond, 2·487; and for chromate of lead it is 3, which substance has a higher refractive power than any other known. Light falling perpendicularly on a surface, passes through it without being refracted. If the light be now supposed to pass from a dense into a rare medium, as from glass or water into air, then R C, R′ C, become the incident rays; and in this case the refracted rays, C I, C I′ are bent from the perpendicular instead of toward it. When the incidence is very oblique, as r C, the light never passes into the air at all, but it is *totally* reflected in the direction C r′, so that the angle p C r is equal to p C r′: that frequently happens at the second surface of glass. When a ray I C falls from air upon a piece of glass A B, it is in general refracted at each surface. At C it is bent toward the perpendicular, and at R from it, and the ray emerges parallel to I C; but when the ray is very oblique to the second surface, it is totally reflected. An object seen by total reflection is nearly as vivid as when seen by direct vision, because no part of the light is refracted.

NOTE 185, p. 148.—*Atmospheric refraction.* Let *a b*, *a b*, &c., fig. 49, be strata, or extremely thin layers, of the atmosphere, which increase in den-

Fig. 49.

sity toward *m n*, the surface of the earth. A ray coming from a star meeting the surface of the atmosphere at S, would be refracted at the surface of each layer, and would consequently move in the curved line S v v v A; and as an object is seen in the direction of the ray that meets the eye, the star, which really is in the direction A S, would seem to a

person at A to be in *s*. So that refraction, which always acts in a verti-
cal direction, raises objects above their true place. For that reason, a
body at S', below the horizon H A O, would be raised, and would be seen
in *s'*. The sun is frequently visible by refraction after he is set, or before
he is risen. There is no refraction in the zenith at Z. It increases all
the way to the horizon, where it is greatest, the variation being propor-
tional to the tangent of the angles Z A S, Z A S', the distances of the
bodies S S' from the zenith. The more obliquely the rays fall the greater
the refraction.

NOTE 186, p. 149.—*Bradley's method of ascertaining the amount of re-
fraction.* Let Z, fig. 50, be the zenith or point immediately above an

Fig. 50.
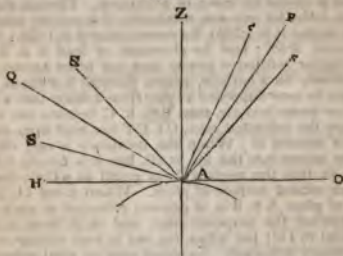
observer at A ; let H O be his horizon, and P the pole of the equinoctial
A Q. Hence P A Q is a right angle. A star as near to the pole as *s*
would appear to revolve about it, in consequence of the rotation of the
earth. At noon, for example, it would be at *s* above the pole, and at
midnight it would be in *s'* below it. The sum of the true zenith
distances Z A *s*, Z A *s'*, is equal to twice the angle Z A P. Again, S and
S' being the sun at his greatest distances from the equinoctial A Q when
in the solstices, the sum of his true zenith distances, Z A S, Z A S', is
equal to twice the angle Z A Q. Consequently, the four true zenith
distances, when added together, are equal to twice the right angle Q A P;
that is, they are equal to 180°. But the observed or apparent zenith
distances are less than the true, on account of refraction ; therefore the
sum of the four apparent zenith distances is less than 180° by the whole
amount of the four refractions.

NOTE 187, p. 150.—*Terrestrial refraction.* Let C, fig. 51, be the
center of the earth, A an observer at its surface, A H his horizon, and
B some distant point, as the top of a hill. Let the arc B A be the path
of a ray coming from B to A ; E B, E A, tangents to its extremities ;
and A G, B F, perpendicular to C B. However high the hill B may be,
it is nothing when compared with C A, the radius of the earth ; conse-
quently, A B differs so little from A D that the angles A E B and
A C B are supplementary to one another; that is, the two taken together
are equal to 180°. A C B is called the horizontal angle. Now B A H
is the real height of B, and E A H its apparent height ; hence refraction
raises the object B, by the angle E A B, above its real place. Again,
the real depression of A, when viewed from B, is F B A, whereas
its apparent depression is F B E, so E B A is due to refraction. The
angle F B A is equal to the sum of the angles B A H and A C B ; that
is, the true elevation is equal to the true depression and the horizontal

Fig. 51.

angle. But the true elevation is equal to the apparent elevation dimin-
ished by the refraction; and the true depression is equal to the ap-
parent depression increased by refraction. Hence twice the refraction
is equal to the horizontal angle augmented by the difference between the
apparent elevation and the apparent depression.

NOTE 188, p. 151. Fig. 52 represents the phenomenon in question. S P
is the real ship, with its inverted and direct images seen in the air.

Fig. 52.

Were there no refraction, the rays would come from the ship S P to the
eye E in the direction of the straight lines; but, on account of the variable
density of the inferior strata of the atmosphere, the rays are bent in the
curved lines P c E, P d E, S m E, S n E. Since an object is seen in the
direction of the tangent to that point of the ray which meets the eye,
the point P of the real ship is seen at p and p', and the point S seems to
be in s and s'; and as all the other points are transferred in the same
manner, direct and inverted images of the ship are formed in the air
above it.

Fig. 53.

NOTE 189, p. 151. Fig. 53 represents the section of a poker, with the refraction produced by the hot air surrounding it.

NOTE 190, p. 153.—*The solar spectrum.* A ray from the sun at S, fig. 54, admitted into a dark room through a small round hole H in a window-

Fig. 54.
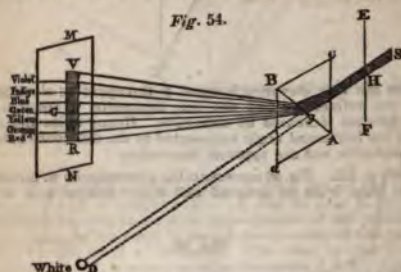
shutter, proceeds in a straight line to a screen D, on which it forms a bright circular spot of white light of nearly the same diameter with the hole H. But when the refracting angle B A C of a glass prism is interposed, so that the sunbeam falls on A C the first surface of the prism, and emerges from the second surface A B at equal angles, it causes the rays to deviate from the straight path S D, and bends them to the screen M N, where they form a colored image V R of the sun, of the same breadth with the diameter of the hole H, but much longer. The space V R consists of seven colors,—violet, indigo, blue, green, yellow, orange, and red. The violet and red, being the most and less refrangible rays, are at the extremities, and the green occupy the middle part at G. The angle D *g* G is called the mean *deviation*, and the spreading of the colored rays over the angle V *g* R the *dispersion*. The deviation and dispersion vary with the refracting angle B A C of the prism, and with the substance of which it is made.

NOTE 191, p. 159. Under the same circumstances, and where the refracting angles of the two prisms are equal, the angles D *g* G and V *g* R, fig. 54, are greater for flint-glass than for crown-glass. But as they vary with the angle of the prism, it is only necessary to augment the refracting angle of the crown-glass prism by a certain quantity, to produce nearly the same deviation and dispersion with the flint-glass prism. Hence,

when the two prisms are placed with their refracting angles in opposite
directions, as in fig. 54, they nearly neutralize each other's effects, and
refract a beam of light without resolving it into its elementary colored
rays. Sir David Brewster has come to the conclusion, that there may be
refraction without color by means of two prisms, or two lenses, when
properly adjusted, even though they be made of the same kind of glass.

Fig. 55.

NOTE 192, p. 159.— The object-glass of the achromatic
telescope consists of a convex lens A B, fig. 55, of crown-glass,
placed on the outside toward the object, and of a concavo-
convex lens C D of flint-glass placed toward the eye. The
focal length of a lens is the distance of its center from the
point in which the rays converge, as F, fig. 60. If, then, the
lenses A B and C D be so constructed that their focal lengths
are in the same proportion as their dispersive powers, they
will refract rays of light without color.

NOTE 193, p. 162.—When a sunbeam, after having passed through a

Fig. 56.   *Fig. 57.*
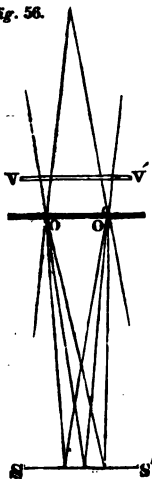
colored glass V V', fig. 56, enters a dark room by two small slits O O' in
a card, or piece of tin, they produce alternate bright and black bands on
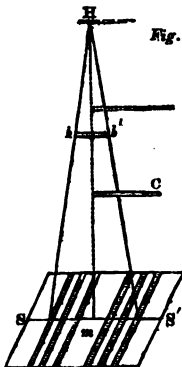
a screen S S' at a little distance. When either one or other of the slits O or O' is stopped, the dark bands vanish, and the screen is illuminated by a uniform light, proving that the dark bands are produced by the interference of the two sets of rays. Again, let H m, fig. 57, be a beam of white light passing through a hold at H, made with a fine needle in a piece of lead or a card, and received on a screen S S'. When a hair, or a small slip of card h h' about the 30th of an inch in breadth, is held in the beam, the rays bend round on each side of it, and, arriving at the screen in different states of vibration, interfere and form a series of colored fringes on each side of a central white band m. When a piece of card is interposed at C, so as to intercept the light which passes on one side of the hair, the colored fringes vanish. When homogeneous light is used, the fringes are broadest in red, and become narrower for each color of the spectrum progressively to the violet, which gives the narrowest and most crowded fringes. These very elegant experiments are due to Dr. Thomas Young.

NOTE 194, pp. 165, 191.—Fig. 58 shows Newton's rings, of which there are seven, formed by screwing two lenses of glass together. Provided the incident light be white, they always succeed each other in the following order:

Fig. 58.

1st ring, or first order of colors: Black, very faint blue, brilliant white, yellow, orange, red.

2d ring: Dark purple, or rather violet, blue, a very imperfect yellow green, vivid yellow, crimson red.

3d ring: Purple, blue, rich grass green, fine yellow, pink, crimson.

4th ring: Dull bluish green, pale yellowish pink, red.

5th ring: Pale bluish green, white, pink.

6th ring: Pale blue-green, pale pink.

7th ring: Very pale bluish green, very pale pink.

After the seventh order, the colors become too faint to be distinguished. The rings decrease in breadth, and the colors become more crowded together, as they recede from the center. When the light is homogeneous, the rings are broadest in the red, and decrease in breadth with every successive color of the spectrum to the violet.

NOTE 195, p. 166.—The absolute thickness of the film of air between the glasses is found as follows:—Let A F B C, fig. 59, be the section of a lens lying on a plane surface or plate of glass P P', seen edgewise, and let E C be the diameter of the sphere of which the lens is a segment. If A B be the diameter of any one of Newton's rings, and B D parallel to C E, then B D or C F is the thickness of the air producing it. E C is a known quantity, and when A B the diameter is measured with compasses, B D or F C can be computed. Newton found that the length of B D corresponding to the darkest part of the first ring, is the 98,000th part of an inch when the rays fall perpendicularly on the lens, and from this he deduced the thickness corresponding to each color in the system of rings. By passing each color of the solar spectrum in succession over the lenses, Newton also determined the thickness of the film

Fig. 59.
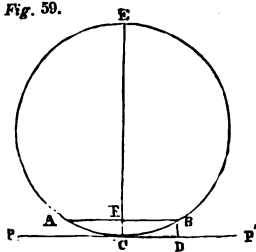
of air corresponding to each color, from the breadth of the rings, which are always of the same color with the homogeneous light.

Fig. 60.

NOTE 196, p. 168.—The focal length or distance of a lens is the distance from its center to the point F, fig. 60, in which the refracted rays meet. Let L L' be a lens of very short focal distance fixed in the window-shutter of a dark room. A sunbeam S L L', passing through the lens, will be brought to a focus in F, whence it will diverge in lines F C, F D, and will form a circular image of light on the opposite wall. Suppose a sheet of lead, having a small pin-hole pierced through it, to be placed in this beam; when the pin-hole is viewed from behind with a lens at E, it is surrounded with a series of colored rings, which vary in appearance with the relative positions of the pin-hole and eye with regard to the point F. When the hole is the 30th of an inch in diameter and at the distance of 6½ feet from F, when viewed at the distance of 24 inches, there are seven rings of the following colors:—

1st order: White, pale yellow, yellow, orange, dull red.

2d order: Violet, blue, whitish, greenish yellow, fine yellow, orange red.

3d order: Purple, indigo, blue, greenish blue, brilliant green, yellow green, red.

4th order: Good green, bluish white, red.

5th order: Dull green, faint bluish white, faint red.

6th order: Very faint green, very faint red.

7th order: A trace of green and red.

NOTE 197, p. 168.—Let L L', fig. 61, be the section of a lens placed in a window-shutter, through which a very small beam of light S L L' passes into a dark room, and comes to a focus in F. If the edge of a knife K N be held in the beam, the rays bend away from it in hyperbolic curves K r, K r', &c. instead of coming directly to the screen in the straight line K E, which is the boundary of the shadow. As these bending rays arr.ve at the screen in different states of undulation, they interfere, and form a series of colored fringes, r r., &c. along the edge of the shadow K E S N of the knife. The fringes vary in breadth with the relative distances of the knife-edge and screen from F.

Fig. 61.
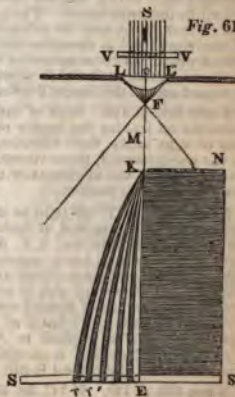
Fig. 73.

—Fig. 73 represents a helix or coil of copper wire, terminated by two cups containing a little quicksilver. When the positive wire of a Voltaic battery is immersed in the cup p, and the negative wire in the cup n, the circuit is completed. The quicksilver insures the connection between the battery and the helix, by conveying the electricity from the one to the other. While the electricity flows through the helix, the magnet S N remains suspended within it, but falls down the moment it ceases. The magnet always turns its south pole S toward P the positive wire of the battery, and its north pole toward the negative wire.

—A copper wire coiled in the form represented in fig. 73, is an electro-dynamic cylinder. When its extremities P and n are connected with the positive and negative poles of a Voltaic battery, it becomes a perfect magnet during the time that a current of electricity is flowing through it, P and n being its north and south poles. There are a variety of forms of this apparatus.

—In fig. 74 the hyperbola H P Y, the parabola p P R, and the ellipse A E P L, have the same focal distance S P, and coincide through a small space on each side of the perihelion F ; and as a comet is only visible when near P, it is difficult to ascertain which of the three curves it moves in.

Fig. 74.
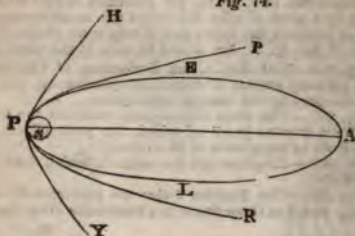
—In fig. 75, E A represents the orbit of Halley's comet, B T the orbit of the earth, and S the sun. The proportions are very nearly exact.

Fig. 75.
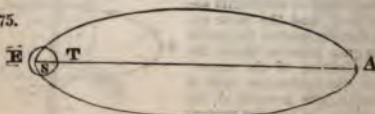
—Fig. 74 represents the curves in question. It is evident that for the same focal distance S P, there can be but one circle and one parabola p P R, but that there may be an infinity of ellipses be-

tween the circle and the parabola, and an infinity of hyperbolas H P Y exterior to the parabola *p* P R.

NOTE 222, p. 371.—Let A B, fig. 26, be the diameter of the earth's orbit, and suppose a star to be seen in the direction A S' from the earth when at A. Six months afterward, the earth having moved through half of its orbit, would arrive at B, and then the star would appear in the direction B S', if the diameter A B, as seen from S', had any sensible magnitude. But A B, which is 190,000,000 of miles, does not appear to be greater than the thickness of a spider's thread, as seen from 61 Cygni, supposed to be the nearest of the fixed stars.

NOTE 224, p. 373.—The mass is found in the manner explained in Note 123 ; but the method of computing the distance of the star may be made more clear by what follows. Though the orbit of the satellite star is really and apparently elliptical, let it be represented by C D O, fig. 14, for the sake of illustration, the earth being in *d*. It is clear that, when the star moves through C D O, its light will take longer in coming to the earth from O than from C, by the whole time it employs in passing through O C, the breadth of its orbit. When that time is known by observation, reduced to seconds, and multiplied by 190,000, which is the number of miles light darts through in a second, the product will be the breadth of the orbit in miles. From this the dimensions of the ellipse will be obtained by the aid of observation, the length and position of any diameter, as S *p*, may be found ; and as all the angles of the triangle *d* S *p* can be determined by observation, the distance of the star from the earth may be computed.

NOTE 225, p. 376.—One of the globular clusters mentioned in the text is represented in fig. 1, plate 5. The stars are gradually condensed toward the center, where they run together into a blaze somewhat like a snowball. The more condensed part is projected on a ground of irregularly-scattered stars, which fills the whole field of the telescope. There are few stars in the neighborhood of this cluster.

NOTE 226, p. 378.—Fig. 2, plate 5, represents one of those enormous rings in its oblique position. It has a dark space in the center, with a small star at each extremity.

NOTE 227, p. 378.—Fig. 3, plate 5, may convey some idea of the ring in the constellation of the Lyre mentioned in the text.

NOTE 228, p. 378.—This most wonderful object has the appearance of fig. 4, plate 5. The southern head is denser than the northern. The light of this object is perfectly milky. There are one or two stars in it.

NOTE 229, p. 378.—Fig. 5, plate 5, represents this brother system.

NOTE 230, p. 379.—Fig. 6, plate 5, represents one of the spindle-shaped nebulæ.

NOTE 231, p. 385.—*Elongation.* The apparent angular distance of an object from the center of the sun.

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PLATE I.

PLATE II.

PLATE III.

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THE END